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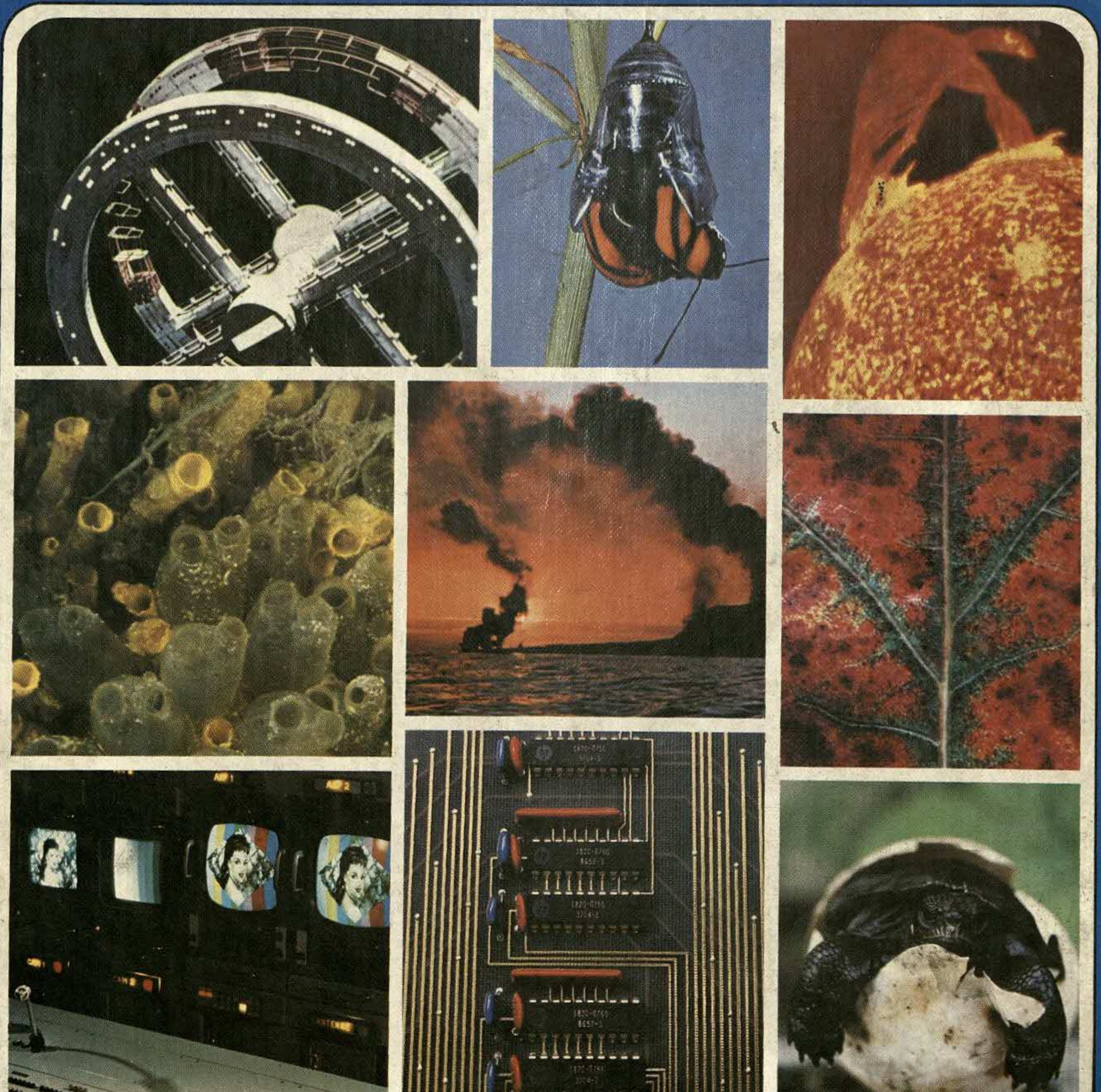
THE NEW BOOK OF POPULAR SCIENCE



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THE NEW BOOK OF
POPULAR SCIENCE

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POPULAR SCIENCE

VOLUME 6

Technology
Appendix
Index

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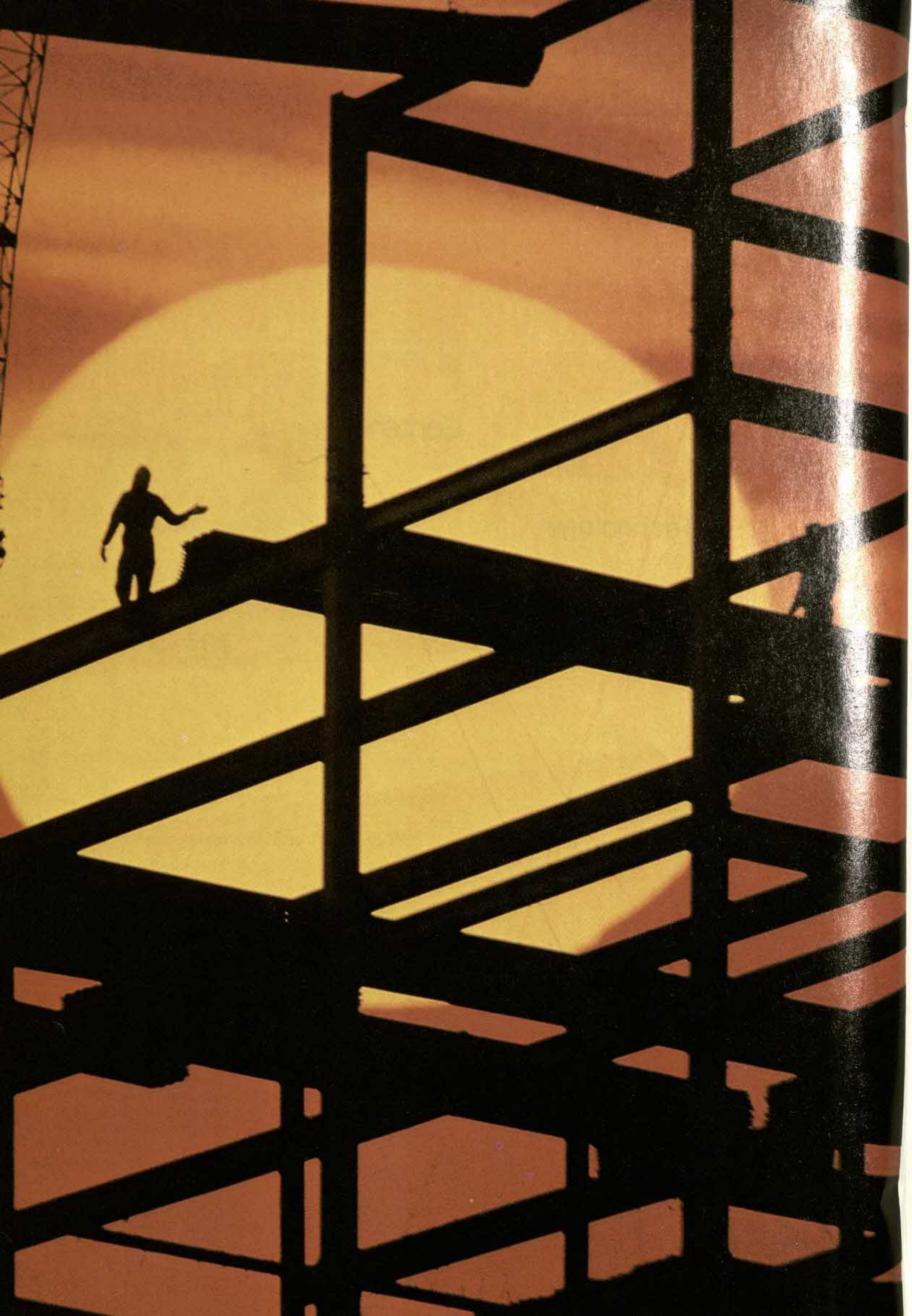
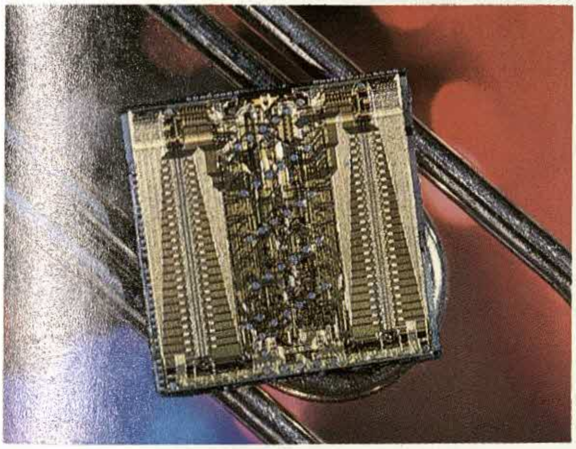


TECHNOLOGY



Left: Don Klump/Image Bank
Above: IBM

First a stone tool . . . Then, the wheel . . . Later, a high-rise building (left) . . . a microprocessor for a computer on a tiny chip much smaller than a paper clip (above). Tomorrow . . .? A technology so big, so complex that most people no longer "belong"?

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Northern Telecom

MODERN ENGINEERING

by Charles N. Gaylord

Television, telephones, synthetic textiles, air conditioning, and fluorescent lighting are a few of the many modern developments we enjoy and take for granted. Many people fail to realize that engineers were in large part responsible for such advances. The members of the engineering profession are continually developing methods, materials, and entire systems so that we may freely avail ourselves of comforts and conveniences that did not even exist a generation or two ago.

It is difficult to find a definition of engineering upon which all authorities will agree. It will suffice, perhaps, to point out that the engineer makes practical use of a knowledge of mathematics and the natural sciences—particularly physics and chemistry—and that, as a result, the materials and forces supplied by nature are made to serve people. In addition to a solid background in mathematics, physics, and chemistry, an engineer must have imagination, ingenuity, and sound judgment if he or she is to design a structure or machine that will be economical, durable, safe, and attractive.

There is a definite distinction between science and engineering. The scientist is usually interested only in extending knowledge of some aspect of the natural world. Scientists want to know why things happen, but are not necessarily interested in useful applications of their discoveries. They usually do not create a product such as a

Monitoring the performance of a computerized automatic communication switching system.

Northern Telecom

steam-turbine electric generating unit. Their ideas and concepts are their products. Scientists isolate new chemical elements, explore the atom, and make discoveries in fields such as dietetics and thermodynamics. They seek answers to questions concerning space, and nuclear physics.

Engineers, on the other hand, are concerned with the intelligent application of scientific knowledge to the solution of technical problems. They want to know not only why and how things work, but also how they can be made to work better and more economically. Engineers must be cost-conscious, because projects are considered practical only if each dollar invested yields a satisfactory return. Furthermore, the engineer has a definite responsibility for public safety.

All this does not mean that there is an impenetrable wall between science and engineering. As a matter of fact, engineers and scientists often work together in the first stages of the applications of new discoveries.

MAJOR ENGINEERING FIELDS

In the preceding paragraphs, we have shown how the scope of engineering has been widened to keep pace with new discoveries in science and technology. At the present time, the profession is broadly classified under seven general fields: (1) aeronautical engineering; (2) chemical engineering; (3) civil engineering; (4) electrical engineering; (5) mechanical engineering; (6) mining, metallurgical, and petroleum engineering; and (7) nuclear engineering. These fields are not separate and distinct, but overlap and merge at many points.

AERONAUTICAL ENGINEERING

This branch deals primarily with the special problems of flight of manned and unmanned vehicles—fixed-wing aircraft, helicopters, ballistic missiles, guided missiles, and space vehicles.

Aeronautical engineers are concerned with the lift force that sustains an aircraft in flight, the drag force resisting flight, and the thrust from the power plant necessary to overcome the drag force. They consider gust loads, which are encountered during a flight when a plane meets a vertical current of air. They also take into account impact loads produced, in landing operations, upon the landing gears of land planes and the hull bottoms or pontoons of sea planes. Flights at very high velocities involve special problems; among other things, they cause the drag force to increase because of the formation of shock waves. The air vehicle is designed so as to ensure stability and control under all these conditions.

Many complex problems involving structure must be solved. If the fuselage or wing of an aircraft is deformed to even a small extent in flight, there may be such drastic changes in the aerodynamic forces

The 121 Xingu turboprop. Air is drawn in, compressed, injected with fuel, and ignited. The combustion gases turn the turbine wheels, which spin the propellers.

United Technologies

acting on the craft that sustained flight will become impossible. The engineer must design a structure that will have maximum strength as well as minimum weight.

The flight testing of aircraft must be carefully and thoroughly planned and conducted. Engineers design, develop, and install test equipment. They direct tests, interpret their results, and then write reports, suggesting design changes, if needed.

CHEMICAL ENGINEERING

Chemical engineers transform the discoveries of the chemical laboratory into useful commercial products. They create new materials and find new uses for old ones. They also develop new manufacturing processes.

Chemical engineering serves both the chemical industry and the different chemical-process industries. There is a basic difference between the two groups. The chemical industry is concerned primarily with the manufacture of chemicals, such as acids, alkalies, salts, explosives, and synthetic detergents. In the chemical-process industries, the ultimate product is not thought of as a chemical. Raw materials have been basically altered through both physical and chemical changes to produce industrial products such as paper, glass, paint, and high-octane gasoline.

Chemical engineers have created preservatives which prevent the growth of fungi in timber. They have developed bottled gas, which has a heat value two or three times that of natural gas, and have made it available for industrial and domestic purposes. At the oil refinery, they produce gasoline, kerosene, fuel oils, and lubricating oils from petroleum. From what remains of the petroleum, engineers direct the manufacture of candle wax, paraffin, petrolatum, and coke. They have developed reliable explosives such as cordite, TNT, PETN, RDX, and the amatols.

Major contributions to the meat-packing, food-preparation, and canning industries have been made by chemical engineers. They have produced fertilizers, glue, and cleaning powders from the wastes of the meat-packing operation. The manufacture of artificial food products, such as margarine and various flavoring extracts, has advanced rapidly because of new processes developed by chemical engineers. They have greatly increased the output of the canning industry by preparing chemical preservatives to maintain the natural color and flavor of foods.

Chemical engineers have created plastics such as Bakelite, cellulose acetate, vinyl resin, phenolic resin, and Plexiglas, and have contributed to the economical manufacture of such varied products as drugs and medicines, cosmetics, perfumes and toilet preparations, paints, pigments, varnishes, and lacquers.

The accomplishments of chemical engineering are impressive indeed. Very likely, more basic research has been carried on in this area than in any other major field of engineering.

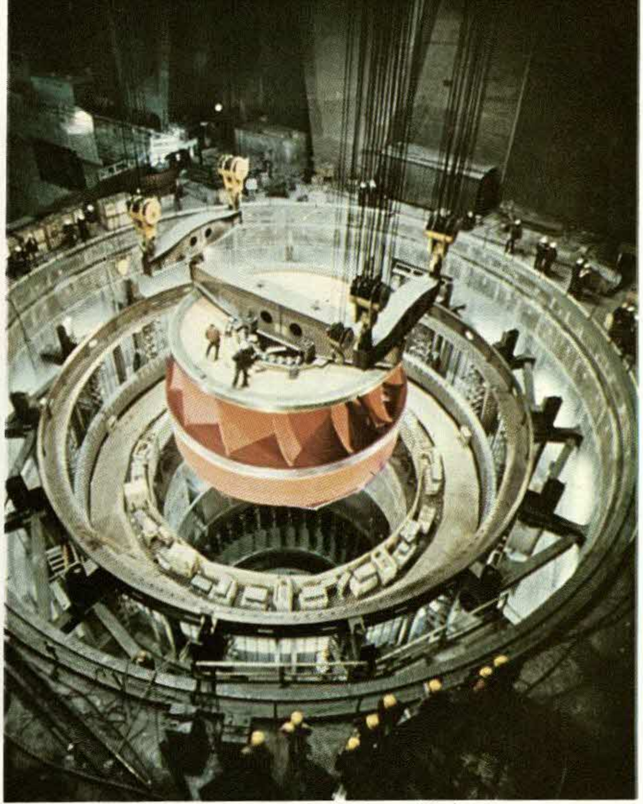
CIVIL ENGINEERING

The scope of civil engineering is wider than that of any other branch of the engineering profession. It embraces the construction of buildings, roads, and bridges; soil mechanics and foundations; water power and irrigation; sanitation; and transportation—in short, activities that have to do primarily with man's environment. Because of the wide range of such activities, civil engineers usually specialize in a particular field of interest within the major branch. It would take several lifetimes of study to be proficient in all aspects of this branch.

Civil engineers design bridges, buildings, transmission towers, storage vessels, dams, stadia, retaining walls, tunnels, docks, wharves, and other structures. The first and often the most difficult problem in such projects is to develop a plan that will make it possible for a given structure to fulfill effectively the purpose for which it is built. Suppose, for example, that engineers are going to construct a highway bridge. It is not enough merely to span a river or a canyon. It is necessary to design the approaches to the bridge, the roadway grade, and the alignment in such a way as to best accommodate the expected traffic. If the bridge is to be over a navigable stream, the engineers have to plan for the necessary clearance, so that riverborne craft will be able to pass under it. They must consider other factors in designing the bridge—for example, the external and internal forces to which the bridge will be subjected—and then work out the proportions of the structural members, select the materials for the bridge, and decide upon the method of construction to be employed.

The *construction engineer* who supervises the erection of a huge plant or skyscraper has to organize and manage a construction force, order materials and equipment, and determine the methods of doing the work. He has to be able to interpret specifications. He must know the safe and economical procedures for erecting tall steel structures, placing concrete, excavating and moving large quantities of earth, and driving piles.

Civil engineers plan, design, and construct water-supply systems, consisting of dams, aqueducts, wells, treatment plants, and pipelines. They provide sanitary systems to collect, treat, and dispose of household and industrial wastes.



U.S. Bureau of Reclamation

The parts of a water-powered generator are being assembled at Grand Coulee Dam in Washington.

The field of transportation offers the civil engineer wide scope. This field is concerned with highway and street systems, railroad right of way, canals, pipelines, and airports.

It requires an advanced knowledge of engineering to locate, design, and construct highways so that they will meet the needs of increasing traffic volume and speed demands. Civil engineers make surveys of the starting points and destinations of the vehicles that will use the highway, study prospective traffic conditions, and take into account intersections with other roads. After all these preliminaries are completed, they must construct a highway that will not only be useful but also pleasing in appearance. Last, but by no means least, they must provide for efficient maintenance after the highway is built.

Civil engineers have an important role in transportation by air. Their duties are to provide adequate aircraft-terminal facilities and to plan for ground transportation between the airports of cities and their business and industrial areas.

Tom Tracy/LIFE Magazine, © 1979, Time Inc.

Nuclear-power plant, Diablo Canyon, California.

NUCLEAR ENGINEERING

The field of nuclear power requires the services of the nuclear engineer. These engineers design and build nuclear reactors in which atomic fission takes place. The reactor has to withstand the terrific quantities of energy released in nuclear reactions and the heat that these reactions produce. It must also have built-in safety features to protect workers and the general public from the deadly effects of atomic radiation.

ELECTRICAL ENGINEERING

There are two main branches of electrical engineering. One is concerned with the generation of electricity to meet the power and light needs of cities and industries. The other covers the application of small amounts of power for communication and various other purposes.

Electrical engineers design the equipment necessary for power generation and transmission, such as switches, conductors, circuit breakers, relays, controls, insulators, bus bars, and lightning protectors. They must solve the problem of providing more and cheaper electricity. They have to build larger generators to convert the mechanical energy of a rotating unit into electrical energy. They must transport this energy economically over longer distances.

Illumination has become a very important field of electrical engineering. It includes the design and manufacture of light sources and reflecting media, and the planning and installation of lighting systems. Electrical engineers are concerned with the lighting of homes, department stores, and industrial plants. They also design floodlighting for airports and recreational areas, special lighting for streets and highways, and decorative lighting in public buildings and exhibitions.

Electrical engineers also play an important part in the field of transportation. They are concerned with power-supply systems for railroads and subways as well as with electrical signaling systems. They also design electrical systems for automobiles and airplanes.

Modern advances in telegraphic and telephonic communication have been due to the electrical engineer. Among the most notable contributions in telephony has been the development of direct long-distance dialing, inaugurated in 1951.

One of the most rapidly expanding areas in electrical engineering is the field of electronics. Everyone knows about such electronic developments as radio, television, and radar. Electronic devices have also been used for precise measuring equipment, computers, and navigational systems for guided missles. They have played an all-important role in automation. They have made possible the remote control of atomic power reactors.

They have also been instrumental in the rise of an exciting new field of astronomy—radio astronomy. It is based on the radio telescope, an electronic device that receives radio-frequency waves originating in the far reaches of our own galaxy and beyond. The radio telescope has enabled the astronomer to map previously uncharted regions of the skies and has provided new insight into the problem of the evolution of the stars and other heavenly bodies. Radio telescopes with a diameter of over 100 meters have been constructed by engineers with imagination and ingenuity as well as technical knowledge.

MECHANICAL ENGINEERING

This branch of the profession has to do with the design and manufacture of all kinds of machines, ranging from extremely delicate instruments to locomotives and railroad cars. It is also concerned with the design and operation of industrial units such as power plants.

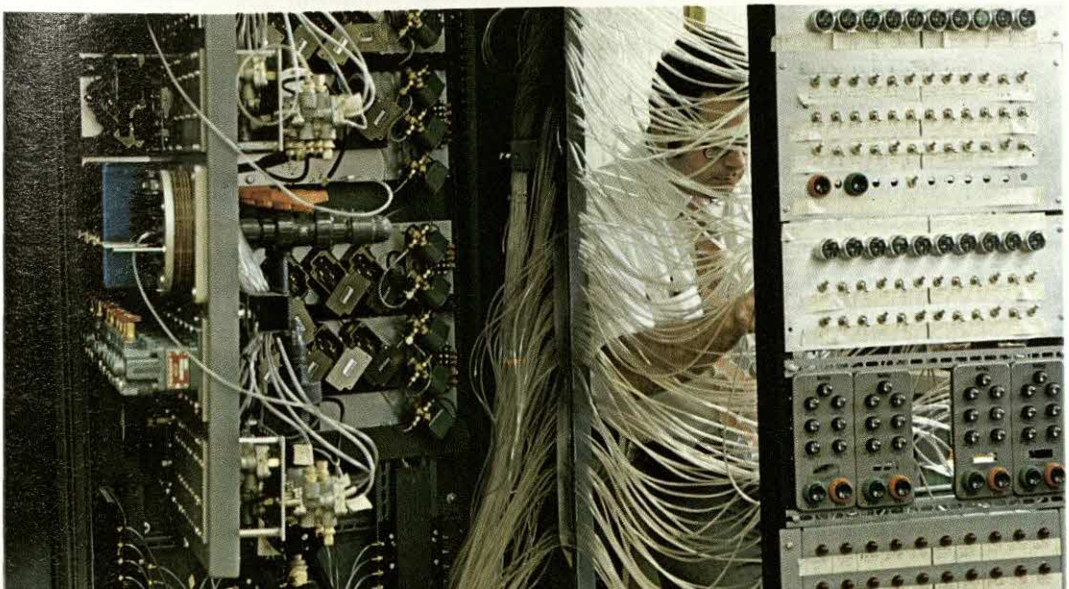
Mechanical engineers who specialize in the field of machine design develop and construct machines to fulfill particular needs. They must have a knowledge of past developments and the ingenuity to produce new combinations of old machine parts and the inventiveness to develop new parts. They must understand how a given machine is to used and must be able to estimate its probable cost and the length of time required for its construction. Engineers select the material to be used and the equipment necessary for its manufacture and then supervise the construction of the machine and arrange a testing program on its performance.

An important task of modern mechanical engineers is to develop complete air-conditioning systems. Some of these will provide comfort in buildings, homes, buses, railway coaches, automobiles, and aircraft. Others will serve industrial purposes in storage, textile manufacture, and printing. Mechanical engineers are also responsible for refrigerating systems used in restaurants, hotels, and markets. They design and build refrigerator cars and trucks for the transportation of perishable products under controlled temperatures.

They work with the architect in designing and installing proper heating systems in

The electrical circuits of an air-control panel are complicated.

Donald L. Miller



United Technologies

The glass-enclosed escalator at the Pompidou Art Center in Paris is the product of modern mechanical engineering and architecture.

buildings and industrial plants. A given system must maintain the desired inside temperature under the most unfavorable weather conditions. Hence the designers must consider such factors as exposure to wind, heat loss due to ventilation, and the difference between the daily maximum and minimum temperatures. They have to take into account the length of time a building will be occupied daily. The fact that we take adequate heating so much for granted is a tribute to the success of mechanical engineers in this field.

Transportation enlists the services of mechanical engineers. They design and build automobiles, trucks, buses, locomotives, freight cars, passenger coaches, ocean liners, freighters, and aircraft. They also are responsible for their power plants—gasoline engines for automobiles; diesel engines for trucks, buses, and locomotives; gas turbines for high-speed jet engines. Mechanical engineers also design and install elevators and escalators for vertical transportation in buildings. They are concerned, likewise, with conveyer belts and other material-handling equipment in factories.

They design the engines that run electric generators in stationary power plants—engines such as steam turbines, hydraulic turbines, internal combustion engines, and gas turbines. Improvements in such machines as well as the development of more efficient boilers and generators have kept the cost of electricity down. This has raised the standard of living, since industry can use more power to do more work.

Industrial management is an important branch of mechanical engineering. People specializing in this field are called *industrial engineers*. They analyze production methods, study wage-incentive systems, employee welfare projects, and labor-management relations. They make recommendations for plant layout and for the purchase of materials.

Mechanical engineers play a vital role in the most advanced phases of modern technology. They have found practical applications for ultrasonic high-frequency waves. They have designed handling and protective equipment for use in nuclear reactors, and they are concerned with power units of guided missiles and rockets.

MINING, METALLURGICAL, AND PETROLEUM ENGINEERING

Engineers specializing in these three fields have long been closely associated. Mining and petroleum engineers search for and extract minerals and are concerned with the conservation of mineral resources. Metallurgical engineers deal with the production of metals from ores and their processing into raw materials for industrial purposes or into products for consumer use.

Mining and petroleum engineers search the areas where petroleum, coal, and other mineral deposits may be located. To obtain the necessary information, they use gravimeters, magnetometers, Geiger counters, sound waves, specially designed cameras, and a host of other devices. After they have located a deposit, they have to decide whether it can be worked profitably. They must take into consideration the cost of mine structures, the handling of materials, the availability of power, the accessibility to market, and the labor supply.

Once it has been decided that a deposit can be economically extracted from the ground, the engineer chooses a mining method. Wells are drilled to obtain petroleum, natural gas, and materials such as sulfur, which can be brought to the surface in a molten state through the injection of superheated water.

Vertical or inclined shafts may have to be sunk to reach deep-lying deposits. Mining engineers must decide upon the size and shape of the shaft. They must keep future requirements in mind, because materials extracted from the mine will have to be passed up the shaft. They have to plan carefully a support system to prevent the roof from caving in as more and more ore is removed. The supports may be pillars of ore left in place for this purpose. They may consist of timber, or rock bolts, or steel sets made up of steel beams, steel arches, and concrete.

Mining engineers have many other responsibilities. They must design and build special machinery for the use of miners and a transportation system to move men, supplies, and materials economically within the mine. They have to install ventilation equipment. They are responsible, too, for the many safety precautions that must be carried out in the mine. They must arrange for the detection and removal of harmful mine gases, such as carbon dioxide, hydrogen sulfide, methane, carbon monoxide, and sulfur dioxide. They must suppress dust within the mine. They also have to control water seeping into mine openings. This may require drainage works.

There are three kinds of metallurgical engineers. The extraction or production metallurgist extracts the metal from its ore and then refines it and prepares it for commercial use. The fabrication metallurgist converts raw metals into various shapes, such as wire, rails, sheets, beams, and girders. The physical metallurgist studies the structure and properties of metals and alloys. He investigates the causes of corrosion and the effects of heat on physical properties. He also develops methods of treatment to increase the strength and ductility of metals.

Tenneco

Mechanical engineers and petroleum engineers worked together to produce this offshore oil-drilling rig.

FUNCTIONS

Engineers perform a variety of functions within the different branches of their profession. They may engage in (1) administration; (2) planning and design; (3) operation and production; (4) construction and installation; (5) research and development; (6) sales; (7) consulting; (8) teaching.

Administration. Engineers with a broad education and a high degree of administrative ability gradually move up to administrative or management positions.

Planning and designing. The planning and design of machines, structures, and processes demand the very highest type of engineering ability. Design engineers have to have a practical background as well as excellent training in theory. They must know the properties of engineering materials. They must be familiar with manufacturing processes in machine design and with construction methods in structural design. Above all, they have to be able to visualize a project as a whole.

Operation and production. The engineer in charge of operation and production is constantly seeking ways of reducing costs and of improving the product or service. He or she introduces new manufacturing

A. Pierce Bounds/Uniphoto

The East Building of the National Gallery, Washington, D.C. represents the latest in modern architecture and engineering.

procedures as required, and is concerned with transportation and communication systems and power plants.

Construction and installation. The construction or installation engineer is one who, by training and experience, is capable of interpreting the plans and specifications prepared by the designer and turning them into reality. He or she supervises all the trades that take part in the construction or installation operation, checks the quality and quantity of production, orders materials and equipment, approves payrolls, and guards against accidents. A construction engineer must get along with and direct other workers. He or she must be able to reach decisions quickly and must have an understanding of costs and efficiency.

Research and development. The research engineer has made priceless contributions to modern industry. Research may result in new materials, such as rayon, nylon, Dacron, Orlon, and other synthetic fabrics. It may bring about the development of automatic machines such as those introduced in the automobile industry—devices that convert rough-cast engine blocks into finished blocks, bored, reamed, and ready for assembly. Research may also lead to new knowledge, such as the development of molecular engineering, by means of which man can make a given material to order.

Sales. Construction materials and equipment, lubricants, and machinery are just a few products which must be sold by men with training in engineering. Their technical knowledge helps clients solve the many complex problems that arise in the use of manufactured goods and services. In addition to a sound technical training, sales engineers must possess the knack of making people like and trust them.

Consulting. A consulting engineer sells his or her services and technical advice to a company, an industry, a political subdivision, an architect, or another engineer. A sound technical training and many years of specialized experience are required.

Teaching. The teaching of engineering is a rewarding profession. It is generally combined with creative professional work in research and consulting. Engineering teachers continue to be students. As they mature, they turn their efforts to more advanced work and to new developments in a particular field. Most of our eminent engineering teachers are also distinguished engineers.

In addition to qualified engineers, there are a great number of engineering aides and technicians, and the need for them is increasing. Generally speaking, they perform the operations for which a complete engineering education is not required.

HISTORY

Engineering is as old as civilization, though the name itself was not employed until the Middle Ages.

ANCIENT TIMES

Five thousand years ago, Egyptian kings and their master builders planned and directed the construction of great temples and pyramids. The Greek historian Herodotus relates that 100,000 men were employed for twenty years to build the Great Pyramid of Gizeh. This structure, 145 meters in height, is still standing. In erecting it, the Egyptians are said to have had only three labor-saving devices: the lever, the inclined plane, and the wedge. Authorities estimate that some 2,250,000 blocks of stone, weighing approximately 2.25 metric tons each, had to be quarried, transported, and placed to complete the Great Pyramid. The Egyptians developed extensive irrigation systems and built many canals. One of the latter connected the Mediterranean with the Red Sea and was the forerunner of the Suez Canal.

The Greeks also made dramatic contributions to engineering. They were the first great harbor builders. They set up rather elaborate water-supply systems, constructed aqueducts by tunneling through small mountains, developed city planning, and advanced the art of building by strengthening stonework with iron reinforcement. They designed and erected many temples, which were sturdy and beautiful. Outstanding among Greek engineers was the great mathematician and physicist Archimedes, who lived during the third century B.C. Renowned for his contributions to mathematics and pure physics, he also made practical applications of scientific principles. He invented the Archimedean screw, a compound-lever device for hauling boats, and military engines.

The Romans imported most of their technical knowledge from the Greeks and, to a lesser extent, from the Etruscans. They showed a strong sense of economy and efficiency. They were great road builders. They also constructed aqueducts and bridges all over the ancient world.

MIDDLE AGES

The Middle Ages are often represented as a period of intellectual stagnation, yet there were some important engineering developments during that time. One of the outstanding ones was the use of gunpowder to fire projectiles set in metal tubes—that is, a cannon. This innovation, dating from the fourteenth century, brought about a revolution in warfare and aroused renewed interest in egineering. Many problems had

The Roman aqueduct at Segovia, Spain.

E. Streichen/Shostal Associates

to be solved before these primitive weapons became effective. Range and elevation had to be studied. The casting of cannon involved the control of metallurgical operations. Military engineers won wide recognition during the period. They were the first to bear the title of engineer, a word derived from the Latin *ingenium*, meaning "mental power" or "invention".

The people of the Middle Ages made other contributions to technology, or applied science. They erected lofty cathedrals, built quite effective water-driven mills and windmills, and set up extensive textile manufactures. A notable technological advance was the invention of printing from movable type about the middle of the fifteenth century.

RENAISSANCE

The Renaissance, which began in Italy in the fifteenth century and spread throughout Western Europe, saw a great boom in applied mechanics. The Italians won particular fame at this time as military engineers. When the universal 15th-century genius Leonardo da Vinci offered his services to the Duke of Milan, he set down among his qualifications his knowledge of fifteen different branches of military engineering. Leonardo, in truth, was a great engineer. He built fortresses, cannon, bridges, harbors, irrigation works, water wheels, and locks. Buried among his notebooks were descriptions of many devices, such as helicopters, parachutes, and submarines, that would have seemed utterly fantastic in his own day. Another important name in technology in the Renaissance was the 16th-century engineer Georg Bauer, better known as Georgius Agricola—the Latinized version of his name. His treatise *Concerning Metals* covers all phases of mining and metallurgy, including ore prospecting, the building of mine equipment, and the assaying and smelting of ores.

MODERN TIMES

Certain great men of science who flourished in the seventeenth century—Galileo Galilei, Blaise Pascal, Robert Boyle, Robert Hooke, and Sir Isaac Newton, to mention only a few—contributed to the advance of engineering by their discoveries in the field of mechanics. Among these contributions were Galileo's law of inertia; Pascal's law concerning the pressure transmitted by a confined fluid; Boyle's law concerning the volume of gases; Hooke's law of elasticity; and Newton's laws of motion.

It was particularly under French leadership in the seventeenth and eighteenth centuries that the art of engineering was expanded and the science of engineering was born. The French established a National Highway Departmennt in 1716. In 1747, they founded the first civil engineering school, the famous Ecole des ponts et chaussées (School for the Construction of Bridges and Highways). Henri Pitot, builder of the Montpelier aqueduct and inventor of the Pitot tube, pioneered in hydraulics. Antoine de Chézy proposed the basic and widely used equation for flow in open channels. Other contributions to mechanics were made by Charles Augustin de Coulomb, Claude-Louis-Marie Navier, and Baron De Prony. All these men also introduced design innovations.

Up to the latter part of the eighteenth century, many persons who were engaged in what we consider today as engineering activities were not called engineers. The only men who bore that title were military engineers, who designed and built weapons and constructed military works serving as protection against an enemy. The 18th century English scientist John Smeaton, designer and builder of the Eddystone lighthouse, was the first man to call himself a *civil engineer*—that is, an engineer engaged in civilian, as opposed to military, activities. Henceforth, the term civil engineers came to be applied to those who built bridges, docks, harbors, breakwaters, and other nonmilitary structures. These men acquired added status with the founding of the Institution of Civil Engineers in 1818.

The steam engine had been developed by Thomas Newcomen, James Watt, and others in the eighteenth century, and had first been used on a modest scale to pump water out of mines. With the coming of the

Industrial Revolution in England in the latter part of the century, steam began to supply power to factories. In the first decades of the nineteenth century, it was also applied to land vehicles and ships. The expansive force of steam offered a far more effective source of power than man had ever possessed before. A new branch of engineering—*mechanical engineering*—was established to make efficient use of this power. Mechanical engineers designed and constructed steam power plants and also the machines operated by the plants. This new branch of the engineering profession was already fairly well established when the Institution of Mechanical Engineers was founded in 1847, with George Stephenson as its first president.

The science of chemistry reached its maturity in the nineteenth century. Chemists now applied to industry and agriculture the many far-reaching discoveries of John Dalton, Jakob Berzelius, Friedrich Woehler, Edward Frankland, Friedrich Kekule, Justus von Liebig, and others. A great variety of dyes were produced from coal tar. Synthetic drugs were prepared. Dynamite was developed by Alfred Nobel. Charles M. Hall and Paul-Louis-Toussaint Héroult made aluminum available in quantity for the first time with their electrolytic process for producing aluminum from aluminum oxide.

In the nineteenth century, too, the principles of electricity revealed by André Marie Ampère, Hans Christian Oersted, William Henry, Michael Faraday, and many others were put to practical use. Samuel F. B. Morse developed the electromagnetic telegraph in the 1830s. In 1844, he amazed the world by sending the message "What hath God wrought!" over a telegraph line between Washington and Baltimore. The first transatlantic cable went into operation in 1858. In 1876, Alexander Graham Bell took out a patent on his recently developed telephone. Three years later, Thomas A. Edison produced the first successful incandescent electric light. In the last decades of the century, the industrial dynamo brought about revolutionary developments.

The electrical engineer took his place in the engineering profession. His field of operation was greatly extended in the twentieth century with the rise of electronics, the science based on the fact that streams of electrons can be made to move outside of conductors. In electronic devices, such as radio and television sets, the electrons are controlled as they move in electron tubes or in solids that are called *semiconductors*.

The *aeronautical engineer* emerged as an important member of the engineering profession with the development of the heavier-than-air flying machine in the twentieth century. Now that satellites and manned space vehicles are a reality, the role of the aeronautical engineer has become more vital than ever.

Greenfield Village and Henry Ford Museum

In 1830 the builder of the steam engine, *Tom Thumb*, raced his engine against a horse to convince the officials of the Baltimore and Ohio Railroad to use locomotives instead of horses . . . the horse won.

A research forester examines test groups of young tree seedlings that are being grown under controlled laboratory conditions. Researchers hope to determine hereditary characteristics, such as resistance to insects and disease, that will help future tree breeding plans.

Weyerhaeuser Co.

FOREST TECHNOLOGY

Wood is a renewable source of industrial material. Unlike most mineral resources, which cannot be renewed within the normal time span of human civilization, many types of trees can be grown again and again, several times in a century. In fact, regrowth may be so rapid that one crop of timber may be harvested once every fifteen to twenty years on a single woodlot. This is especially true where large or mature trees are not necessary, as in the production of wood pulp. All of this has been made possible by the development of modern forestry techniques. There has been a wide-scale application of machinery in the harvesting, transportation, and processing of wood, as well as in the reduction of waste in logging and mill operations. Moreover, any wastes that are produced are now turned into useful industrial products. Today, 60 to 80 per cent of a tree is used profitably, as compared to 40 or 50 per cent in 1950 and only 30 per cent in 1900.

The structural use of wood, in constructions such as buildings, bridges, ships, and so on, has undoubtedly given way in many areas to metal, plastics, glass, concrete, and other materials. As a fuel, wood has been replaced by coal, oil, natural gas, and atomic energy. But enormous quantities of timber are still consumed for various purposes, particularly in the construction of buildings, framework and scaffolding, furniture, utensils, handles, and various containers. A tremendous demand for wood is made by paper and pulp mills, by the chemical industries, and by plywood and hardboard manufacturers. Despite the tremendous demands these activities make on our forest resources, the timber supply in some parts of the world is increasing, because of management of forests and good timber-harvesting practices.

SOME DEFINITIONS

Forestry can be defined as the management of forest lands for the continuous production of their products and use of their lands for recreation and other purposes.

Timber is a broad term applied to standing trees, as well as to the various structural forms of wood made by man, such as logs, lumber, poles, posts, railroad ties, shingles, pilings, and so on. *Lumber* is used for the sawed sections of logs to be made into boards and planks, as well as for the boards themselves. *Sawtimber* and *sawlogs* indicate the trees and logs, respectively, that are to be sawed into lumber and various other forms of timber.

Hardwood is the wood of deciduous

trees, such as oak, maple, hickory, and so on. The wood, however, is not always so hard. Hardwood is often used in the manufacture of furniture, tools, handles, and interior paneling, as well as in the chemical industries and to some extent in pulp and paper production. The wood of evergreen trees, or conifers—pine, fir, spruce, and so on—is called *softwood,* although it is not always soft. It usually goes into the construction of homes, frameworks, scaffolding, veneers, plywood, boxes, crates, and other containers. A huge volume of softwood is utilized in the chemical, pulp, and paper industries.

In heavily industrialized areas, a large proportion of the wood is not used in its more or less original structural form, but is transformed into other kinds of materials. *Veneers* are thin sheets cut from hardwoods or, more often, from softwoods. Veneer is often used to face inferior kinds of wood. The veneers may be bonded together to form *plywood,* which usually consists of a number of sheets held by adhesive so that their grains are at right angles to each other.

Logs and other pieces of wood are often broken down into small fragments, which serve as the starting point for a diversified array of industrial products and materials. The wood is disintegrated by several methods into flakes, chips, shavings, and smaller particles and fibers, either deliberately or as the result of logging and sawmill operations. In the latter case, these fragments, once considered wastes, are now converted into useful materials. For example, *hardboard* is an artificial woodlike substance manufactured from disintegrated wood fibers that are bonded together under high pressure. *Flakeboard, chipboard,* and *particleboard* are composed of wood flakes, chips, or particles, respectively. bonded together with glues. Sawdust and bark fragments, by-products of logging and mill operations, are used as industrial raw materials. So-called *wood flour,* very finely ground wood, goes into the manufacture of linoleum, plastics, and explosives.

Timber that is to be disintegrated into small fragments, known as *wood pulp,* is designated as *pulpwood.* The pulp is used very often to fabricate paper, paperboard, rayon, and cellophane. A great many valuable substances are developed as by-products of the pulpmaking process.

Many other products are obtained from trees and not only from the wood alone. Resin from certain species of pine is distilled into rosin, turpentine, and other substances. Nuts, fruits, and seeds are gathered from trees. Maples yield sap for syrup. Oil comes from pine and cedar needles. Bark is a source of waxes, mulch, cloth, insulation, and tanning materials. The osage orange tree produces a dye. And, during the Christmas season, millions of evergreens are harvested for decorations.

PRODUCTION AND CARE

Before the twentieth century, the forests in many parts of the world were ruthlessly exploited by industry or extensively cut down to clear land for agriculture. The resultant waste and damage to the land became so shocking that conservation movements were organized to save what was left and to restore as much as possible. Governments—largely through forest-use laws—as well as lumber companies and private individuals took important steps in the application of sound forestry and logging practices. Breakthroughs in the fields of disease and insect control, breeding, planting, and fire control all contributed to sound forest-management practices.

TREE FARMS

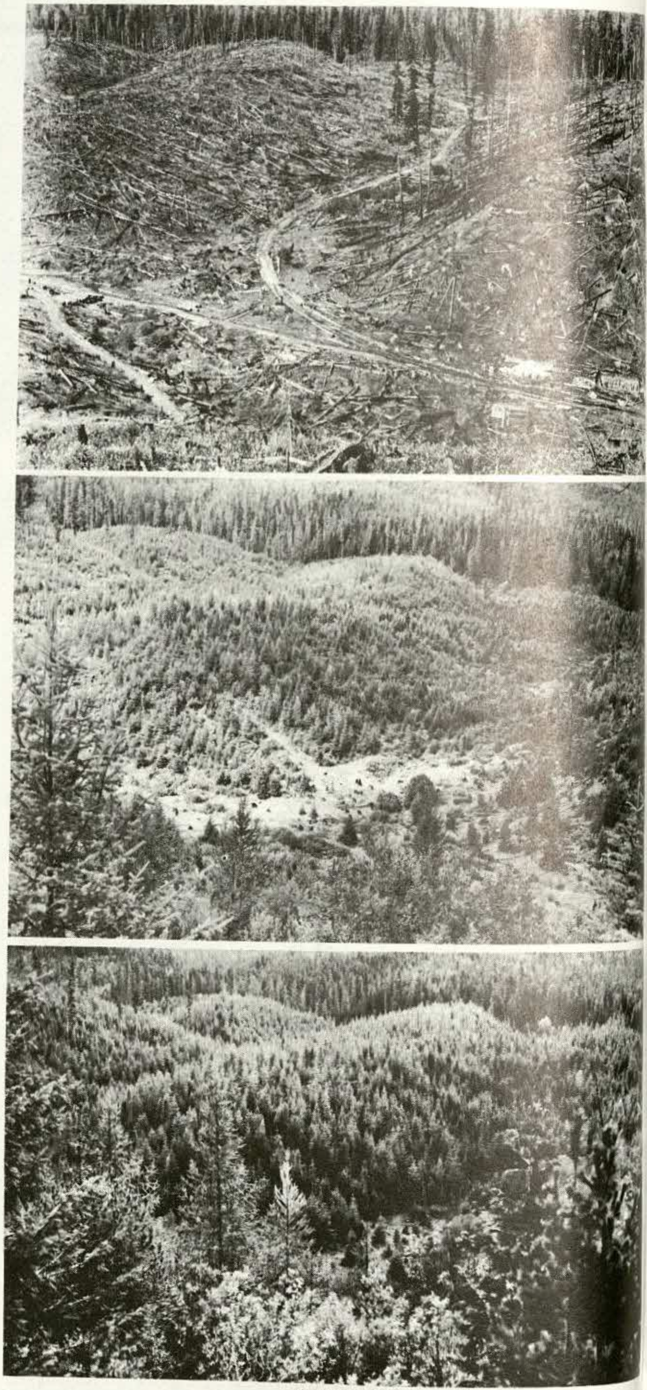
One of the most potent methods in the reforestation of land with commercially valuable timber was the introduction of the tree farm system. The *tree farm* is literally what its name implies —a farm for the growing of trees for economic harvesting and profit. Rigid standards of growing, maintenance, and harvesting of trees are set up. Plots of land are given over entirely or in part to the production of commercially useful trees. The wood is sold to lumbering or papermaking corporations, with profit to the tree-farm owners.

MULTIPLE-USE CONCEPT

Much of the recent progress in commercial forestry has also been due to the wide-scale application of different biological sciences. The woodland is a balanced ecologic unit, involving complex relationships among trees and other plants, and animals and man. Recognition of this fact has led to the adoption of the *multiple-use concept*. A forest is now looked upon no longer as merely a source of timber, to be exploited. It is a home for animals, as well as an area of recreation for camping and sports. Most lumber and paper companies encourage hunters and fishers to use their woodlands for their activities. Their numbers are controlled, and they must promise not to damage the trees wilfully nor to destroy game wantonly. It has been found that thinning of forest stands encourages the reproduction and growth of many forms of animal life, as well as useful plants other than trees. On the other hand, the presence of too many animals, particularly deer, beaver, and bear, harms the forest, because these creatures feed upon or otherwise kill the trees. Therefore, hunting is necessary to keep down the numbers of game. Ultimately, the forest will be cut down, but it will grow back fairly soon.

LIKE AGRICULTURE

Certain modern forest practices are startlingly like those in agriculture. They include planting, transplanting, cutting and grafting, harvesting, and so on. The forestation or reforestation of a land tract may be accomplished by means of merchanical tree planters or seeders on the ground or by seeding from the air, with planes and helicopters. Timberlands must be weeded, to remove trees of no commercial value which invade the area and compete with valuable trees for soil, water, and sunlight. Diseased trees must also be removed. If possible, their timber is used commercially. The deliberate thinning out of tree stands stimulates the rapid growth of the remaining trees, and the pruning of branches improves the quality of individual trees. Fertilizers may be added to the forest soil.



all photos, U. S. Forest Service

Series of photos in Willow Creek area of St. Joe National Forest in Idaho. Top: 1938 photo showing logged area. Middle: 1949 photo, showing the area 10 years after reforestation. Bottom: 1969 photo showing new forest.

Spraying of trees against insects and disease is needed. Fire prevention is a must.

Other important forest-production, or silvicultural, methods involve the breeding of new tree types featuring rapid growth, high timber yield of excellent quality, disease- and insect-resistance, and so on.

TIMBER HARVESTING

The removal of trees for ultimate conversion into useful products is known as timber harvesting, or *logging*. Selective logging involves the cutting only of those trees that are most suitable for the purposes in view. Mature, overmature, poorly formed, diseased, or insect-infested trees are often taken. Other trees may be left standing, usually because they are young and still adding wood at a rapid rate. The trees that remain are also intended to reseed a cutover area, so that more trees will grow. If an entire stand of timber is cut down, a new forest may start to grow by itself, or else the tract will be replanted or reseeded by man.

Timber harvesting consists of the following basic operations: the cutting down, or *felling*, of the trees; the removal of limbs, or *limbing*; the cutting of the trunks and the heavier boughs into logs of suitable length, a practice known as *bucking*; the local hauling of logs and trees in the cutting area to some point of storage or further transport, a technique called *skidding, yarding*, or *prehauling;* and then the final transportation of the cut timber to the sawmill or pulp or paper mill. After an area has been logged, there is often a follow-up operation to retrieve various pieces of wood, branches, bark, and even stumps which may prove to be of commercial value.

Felling, limbing, and bucking. Timber harvesting is becoming increasingly mechanized. Today felling, limbing, and bucking are accomplished by means of power saws of various types. A tree must be cut so that it falls in a desired direction, with a minimum of damage to itself and nearby standing trees.

Smaller trees that will become pulpwood may be felled by a machine, such as the Bushcombine in use in the southeastern United States. Another type of forest machinery (the Utilizer) can be moved into a wooded area to cut logs up into chips and flakes on the spot, instead of at a pulp or paper mill.

Skidding. The local hauling of cut trees and logs is carried out in various ways, depending on the scope of the harvesting operation and the nature of the terrain. The term skidding was originally derived from the practice of dragging (skidding) logs along the ground or along a special kind of trail known as a *skid road.* The operation was done by different methods. Lumbermen themselves handle single small logs with hooks called *peavies*.

Much local hauling of logs is carried out by simply loading them on a vehicle of some sort. Special machines can move quite a few logs at a time, loading or unloading the carriers. The logs are finally hauled out of the forest on trucks or trains. The vehicles used in all these activities must usually be able to move over rough terrain, in areas where there are no roads or only poor ones.

Hauling may be practiced with cable systems. The felled trees or logs are dragged or even lifted by a system of cables that are rigged to one or more upright masts, or spars, and powered by a diesel or gasoline motor. The spar tree is now usually a high metal spar or pole that can be moved readily into position and then rigged in only a few hours. Cable hauling is often employed in rough country where wheeled vehicles would have a difficult time.

Balloon skidding of logs is also used in mountainous areas. A large helium-filled balloon is guyed in place, and pulleys and cables are attached. Several metric tons of logs at a time can then be lifted and carried to a central point for loading on trucks.

Final hauling. Generally trucks and in certain instances railroads haul the felled logs and other pieces of wood to the sawmill, pulp, or paper mill. In some areas, streams and lakes are also used for the storage and movement of logs. Wood-processing plants need no longer be located close to the site of logging operations, and today they are frequently hundreds of kilometers from the forest.

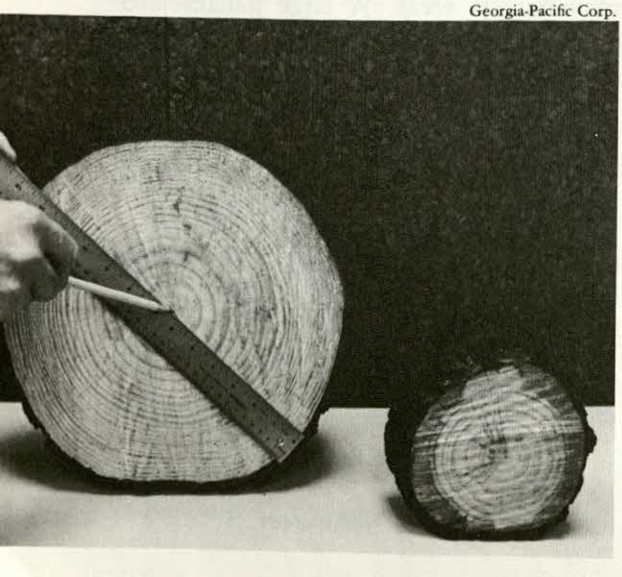
THE MANUFACTURE OF WOOD PRODUCTS

Once the logs have reached the mill, the industry of converting them into useful products begins. The wood is sorted in various ways. The wood mill is a complex operation that often combines the manufacture of lumber, pulp, veneer, and other products.

Lumber. The manufacture of lumber involves the sawing of logs lengthwise into sections of various thicknesses, lengths, and widths, to produce *boards* or *planks*. The logs are first washed and have their bark removed. They are then drawn up by a huge chain or other mechanical device toward the so-called *head saw*. This may be of the familiar rotary, or circular, type. In larger mills, it is a band saw, consisting of a toothed "endless" steel band moving vertically on a pair of rapidly turning wheels. A log moves on a traveling bed or carriage against the head saw in a lengthwise direction. The saw cuts a section from the log. The log then moves back to its former position and is shifted laterally for another cut. The saw operator, or *sawyer*, determines the locations of cuts to be made and, therefore, their number. The log then moves forward to the head saw, which cuts off another section. This process is repeated until the log has been sawed into a number of rough boards and thicker pieces known as *cants*, or *flitches*. These sections then move on rollers through a series of different saws that cut the sections into boards of different widths. Still other types of saws finally cut the lumber into desired lengths and widths and also remove the defects.

In a well-managed forest, tree growth is faster than in an unmanaged one. These sections are from 27-year old trees. The one on the left comes from a managed forest.

Georgia-Pacific Corp.

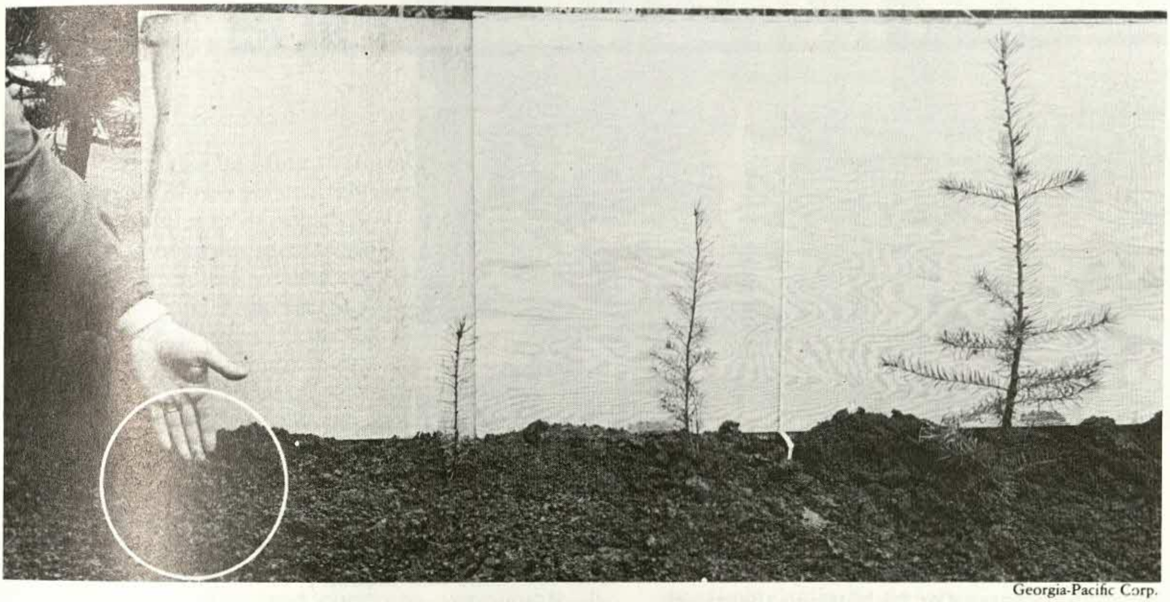


Conveyer belts or chains next move the boards into a special shed where they are graded by trained men according to quality. The lumber is then seasoned or dried, either in the open air or in special drying kilns. In the planing mill, the rough-cut lumber may be smoothed by mechanized knives into so-called *finished lumber*. The boards may also be worked into various forms for use in building construction.

In most sawmill operations today, the logs are *debarked*, or have their bark removed, before being sawn. The bark is used industrially in the manufacture of an astounding variety of products, including adhesives, dyes, drugs, tannins, insulation, and so on. The sawdust produced also gives rise to numerous useful substances and products. Various kinds of specialized mills also produce different kinds of timber products—railroad ties, barrel staves, and other types of structural wood shapes.

Veneer and plywood. The principles involved in the production of veneers and plywood are quite different from those applied in the manufacture of lumber. Here a previously steamed log is turned on a lathe against a large knife. This causes the log to be "peeled," so that a continuous sheet of thin wood is "unrolled" from it. In another method of cutting, a flitch is moved up and down against a stationary knife, which at each pass cuts off a slice of wood to be made into plywood or veneer. Another method produces half-round veneer, which is intermediate in shape between rotary-cut veneer and sliced veneer. A certain quantity of veneer is still made by means of a circular saw. Softwoods are primarily used in the manufacture of plywood and veneer.

The wood sheets then pass to a clipping machine, which cuts them into various sizes. The sheets are then heated in special drying chambers. Not all the moisture is re-



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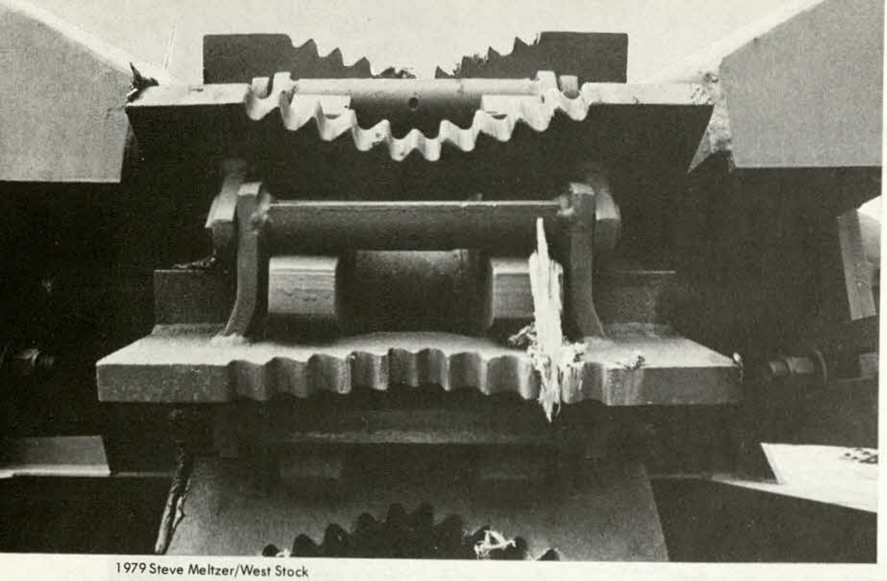
These Douglas fir seedlings show size differences between seedlings grown in a natural forest that has been reseeded and "super'" seedlings developed by researchers to speed tree growth. (left) Tiny one-year-old natural seedling and a one-year-old super seedling. (right) Two-year-old prime seedling and super seedling.

moved (somewhat over 90 per cent of it is). Then the sheets pass to taping or splicing machines, which join them into larger-sized sheets. During these operations, defects are removed or repaired. Next, glue is applied to the wood sheets, by means of spreaders with rollers, through which the sheets pass. Finally, the sheets, or veneers, are pressed together in large presses at pressures of anywhere up to 20 kilograms per square centimeter. Heat is often applied. Cold presses may be used. The resulting panels or plywood are then conditioned, cut to various sizes, and perhaps treated in other ways.

Many kinds of veneers and plywoods are manufactured, depending on their uses and the qualities required. Wood sheets may be bonded with other materials, such as metals and plastics, for special requirements. The nature of the glues also affects the durability of the plywood. Definite grades of veneers and plywoods exist. The best are used where strength or beauty is required. Veneers are used to face less attractive and inferior wood, as in furniture and other products. Softwood plywood is used by manufacturers in an extraordinary range of goods.

Hardboard. Hardboard is a general term denoting a kind of synthetic wood produced when fibers of disintegrated wood are bonded together under intense pressure. There are a number of other synthetic wood materials, depending on the nature of the fragments and how they are joined. *Flakeboard* is composed of flat wood shavings bonded with synthetic resins. *Particleboard* consists of wood particles glued together with synthetic or other resins. Hardboard, on the other hand, does not normally require the addition of synthetic glues, because it contains the natural adhesive present in wood, a substance known as *lignin*.

In the manufacture of hardboard, logs and odd pieces of wood from a variety of trees are reduced to chips in a machine with rotating knives. These chips are then broken up into their component cellulose fibers in machines that mechanically disintegrate them or explode them under steam



This powerful tree barker quickly strips the bark from logs, which are then processed into boards.

1979 Steve Meltzer/West Stock

pressure. The fiber masses are further refined into individual fibers. Then these fibers are formed into an interlocking mat by a variety of methods—by means of water on a screen or by blowing them with air onto a metal cone. The resulting fiber mat is passed through rollers and then fed into giant hydraulic presses, which form it into thin, dry boards under heat and pressures of up to several kilograms per square centimeter. Next, the boards are humidified in a special chamber. This is to prevent warping.

Finally, the hardboard is sawed into various shapes and sizes. Hardboard is extremely strong and resistant to marring and damage. These properties make hardboard particularly ideal for paneling. There are many varieties of hardboard that are available. They are suitable for the manufacture of siding, furniture, tabletops, and other kinds of construction.

PULP AND PAPERMAKING

Vast quantities of wood are pulped and further disintegrated in various ways to provide raw material for the manufacture of paper and paperlike products, plastics, and various chemicals. The disintegration may be carried out in several ways—mechanically or chemically or various combinations of these two basic methods. The manufacture of paper is a complex process requiring the use of many chemicals and machines. Residues from papermaking are converted into useful products and chemicals.

CHEMICAL WOOD PRODUCTS

Wood is transformed through chemical change into an incredible variety of products for home and industry. In this respect, wood is as versatile as any other raw material. The results of wood distillation are such materials as charcoal, acetic acid, acetone, wood alcohol, pitch, turpentine, rosin, tars, and oils, and other chemicals. The type of product often depends on the kind of wood distilled.

Wood treated chemically in other ways yields a wide variety of other products, including acetic acid, yeast, ethyl alcohol, sugars, glycerine, and resins. Wood-byproduct chemicals are further used in the manufacture of a considerable number of other chemicals and products.

MISCELLANEOUS FOREST PRODUCTS

Sawdust is the raw material for numerous products, such as synthetic materials of various kinds, absorbent matter, pulp, animal feed, filters, insulations, plastics, and various molded objects, among other things. Naval stores—rosin, turpentine, pitch, and other chemicals—are produced from the resin of various species of pine (such as slash and longleaf), particularly in the southeastern part of the United States. Balsam is obtained from fir trees. It is used in medicine, cosmetics, sealing waxes, and optical instruments, and research. A variety of oils and fibers are obtained from the different parts and even the fruits of trees.

BUILDING TECHNOLOGY

by John H. Callender

All building materials may be divided into three general classes: primitive, traditional, and modern.

Primitive materials are readily available in nature and require very little preparation. They include logs, saplings, reeds, leaves, grass, skins, clay, and snow.

Traditional materials are those that have been in use over a long period of time and that require more or less extensive preparation. Stone, brick, tile, mortar, timber, plaster, metal, and glass are examples of traditional materials.

Modern materials include new or relatively new substances such as structural steel, reinforced concrete, vermiculite, fiberboard, plywood, and plastics.

PRIMITIVE MATERIALS

We think of a builder nowadays as a specialist who devotes all his time to his chosen lifework. But the history of building with primitive materials generally shows no such specialization.

Perhaps an example or two will make this clearer. Colonists in a new land frequently must clear away trees. They then often take these trees to make a shelter for themselves. Selecting trunks that are straight and uniform in size, they place one on top of another, notch and lap the corners, and build a log cabin.

The various tribes of North American Indians built with different primitive materials. The tribes of the western plains were hunters. They made their houses of animal hides, stretched over a pyramidal frame of saplings.

Primitive materials are generally used in their natural state, without processing, but this is not always true. Many Arabs live in tents of cloth woven from sheep's wool, goat's wool, or camel's hair. In Mongolia the tents are covered with felted cloth.

TRADITIONAL MATERIALS

Unlike the primitive materials, traditional materials require some preparation before they can be used for building.

STONE

For thousands of years, stone has been without a rival as the material for buildings of a monumental nature—that is, those that are intended to endure and to have dignity and authority. We find the earliest monuments of this sort in ancient Egypt.

In Greece, too, the inhabitants turned to stone for building after wood became scarce. The architecture of the Hellenic civilization, executed in white marble, has been a major influence in Western architecture.

The Romans built first of brick, but as they came under the influence of Hellenic culture, they, too, found stone more beautiful. They often put up walls of brick, or rubble, or concrete, and faced them with thin slabs of stone.

One of the disadvantages of stone is

In ancient Greece, the traditional building material of choice was white marble. Rows of evenly spaced columns provided support for overlying structures.

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the short distance that a single stone spans between supports. The Romans solved this problem: they developed the *arch* as a way of increasing span and used it extensively in its various forms, especially the vault and the dome, which permitted them to build vast open halls, uncluttered by columns.

Most desirable are the even-grained stones that are fairly easy to cut, such as *sandstone, limestone,* and *marble*. In *rubble,* or *roughwork, masonry,* as distinguished from *ashlar,* or *cut stone masonry,* practically any type of stone may be seen. The exposed face of stone masonry may be given various textures: highly polished, carved, or extremely rough.

BRICK AND TILE

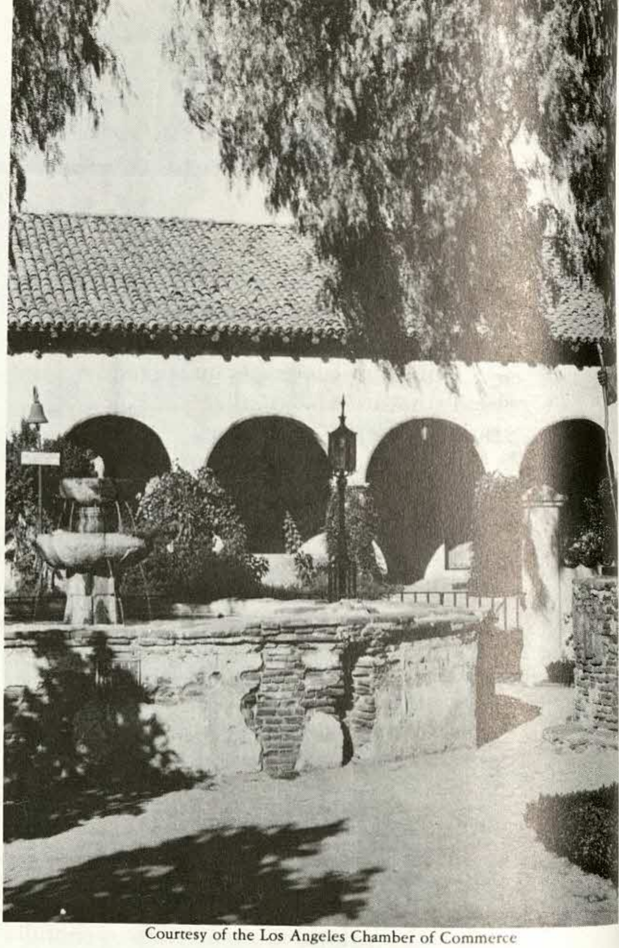
Second only to stone as a permanent building material and second only to wood as a utilitarian material is brick. It is made of clay, molded into blocks while moist and then hardened in the sun or by fire. Standing midway between wood and stone in cost, brick has long been used as a substitute for these materials.

The first bricks were hardened by being exposed to the sun. Then the people in Mesopotamia discovered that if bricks were baked in an oven, they would be much harder and more durable.

Bricks are always laid in mortar. The type of mortar, the width of the joint, and the skill with which the work is done all have an important effect upon the appearance, the durability, and the waterproof qualities of a brick wall.

A wall consists of at least two thicknesses of brick. In order to tie these two thicknesses together, some of the bricks are turned so that their length extends back into the wall, and only their ends are exposed. These *headers,* as they are called, may be arranged to form a pattern, which can be quite decorative. In modern times, brick walls are sometimes built with a more or less continuous hollow space between the two thicknesses. This gives better insulation and keeps water out.

In order to span even a small opening in brick masonry, an arch must be built, or a *lintel* (beam) of other material used.



Courtesy of the Los Angeles Chamber of Commerce

This mission in southern California is a fine example of stucco construction. The roof is made of baked clay tiles.

The Babylonians discovered that, if certain minerals and pigments were added to the surface of clay, they would melt during the firing and form a hard, smooth, glazed surface. Glazed clay, generally in thin, flat shapes, called *tiles,* later became an important building material. Tile has been used for decoration by most people who have built extensively in brick. The medieval Mohammedans carried tile to its highest point of development, especially in the Middle East and Spain.

WOOD

Wood is the world's great utilitarian building material. Probably there are more buildings of wood today than of any other substance that is used for building purposes.

Wood is in some respects ideal for

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building purposes. It is still plentiful in many parts of the world and could be grown as a crop in most other places. Unlike the masonry materials we have been discussing, it is light but very strong for its weight. It is easily worked, is a good insulator, and is warm to the touch and springy to the step. It also has certain disadvantages. It is flammable, apt to decay, and shrinks or swells with changes in moisture.

In wood, moderately long spans are easily provided and extremely long spans are quite practical, with the aid of trussing, or bracing. In a few parts of the world, notably Scandinavia and Japan, wood has been used throughout, even for the most monumental buildings.

PLASTER AND STUCCO

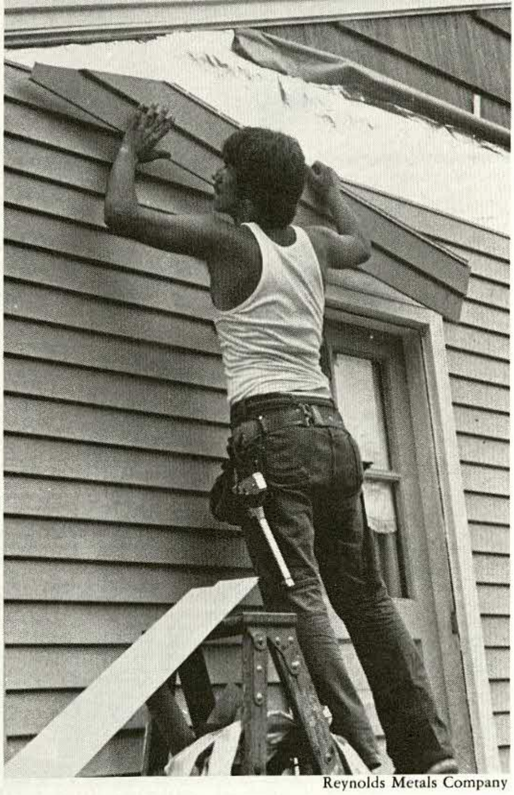
Plaster is of ancient origin and has been used all over the world, especially for interiors. A wall may be built with considerable roughness and inequality and with no consideration for appearance if it is later to be plastered. A plastered wall or ceiling can be made to produce an unbroken, smooth white surface, which cannot be achieved by any other means. Plaster may be given various surface textures, or it may be molded or colored, as it is applied. Mural paintings done on wet plaster are known as *frescoes,* and their beauty, as well as their durability, may be seen in the examples uncovered at Pompeii and on Crete.

Interior plaster has generally consisted of sand and lime, with some fiber or hair to give it additional cohesion. Gypsum often takes the place of lime, or it may be added.

Exterior plaster, usually called *stucco,* must be more waterproof and more resistant to freezing and thawing than interior plaster. Stucco consists of cement and sand with a small amount of lime. It has been widely applied to buildings to cover rubble masonry or poor brickwork.

METAL

Until modern times, metal was not a primary building material, but it has long served in connection with other materials. Bronze, a mixture of copper and tin, was sometimes concealed in stone masonry to key the stones together. Doors, windows, grilles, railings, hardware, lighting fixtures, fountains, and even bathtubs were made of bronze by the Greeks and Romans. Copper, which can be pounded into thin sheets, has long served for roofing, gutters, and downspouts. It has also provided *flashing*—waterproofing material used to seal a joint in the roof or between the roof and another part of the building. Copper makes fine water piping, because it is fairly resistant to corrosion. Since ancient times lead has been used for roofing, flashing, gutters, downspouts, and water piping. Tin, another noncorroding metal, is used in roofing and flashing, tin coating, and solder.

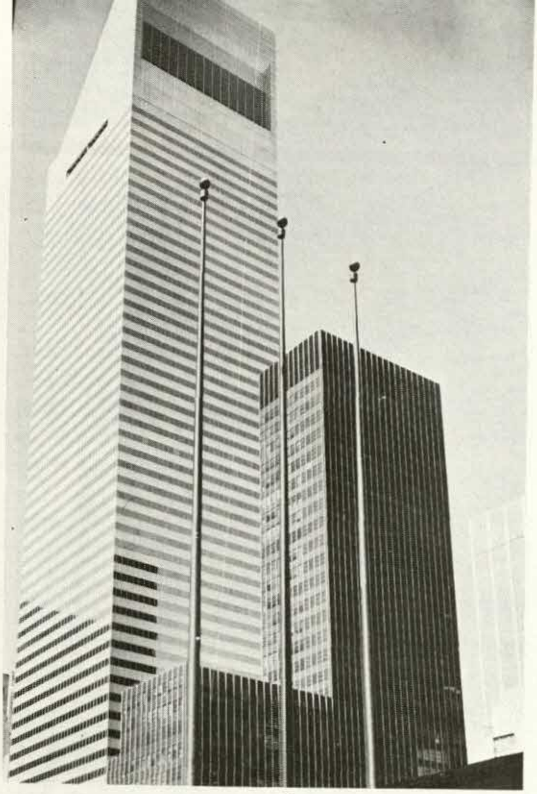


Reynolds Metals Company

Aluminum, shown here as siding, is an example of a modern material. Many modern materials are maintenance-free.

Zinc's most important use today is for coating steel, or *galvanizing*. Zinc roofing, flashing, and weather stripping are not uncommon. Brass, a mixture of copper and zinc, serves principally for water piping, door hardware, and lighting fixtures.

Wrought iron, hand-forged by skilled blacksmiths, was the only form in which



© Louis Goldman/Photo Researchers

The Citicorp Center in New York City, with its characteristic angled roof, is an outstanding example of the use of glass and steel in modern skyscrapers.

iron had a place in construction until comparatively modern times. In the Middle Ages, it was popular for door hardware, lighting fixtures, railings, and grilles.

GLASS

Glass has been used for windows since Roman times, but not until the late Middle Ages did it become a major item in building. Then, in northern Europe and England, not only the great cathedrals but also royal palaces, town halls, city houses, and other types of buildings were opened up with huge expanses of glazed windows. Medieval glass was in small pieces, only a few centimeters in each dimension. These were set in lead *cames*—that is, grooved bars of lead that formed a resilient and watertight frame. The glass was hand-blown and quite irregular in surface, texture, and color, but it let light in.

MODERN MATERIALS

Toward the middle of the nineteenth century, building began to feel the effects of the Industrial Revolution. Much work that had been done by hand could be done more cheaply by mass production in factories. New materials were introduced. The most important were steel, reinforced concrete, insulation, and sheet materials.

IRON AND STEEL

The first iron bridges were built in Great Britain in the 1840s. As early as 1851 the Crystal Palace, originally set up in Hyde Park, in London, was built entirely of iron and glass. In 1889, Gustave Eiffel made the world gasp by building an iron tower in Paris to the dizzy height of almost 300 meters.

It was in Chicago, Illinois, in the 1880s that the complete steel frame was first used. The steel frame is a continuous cagework of steel columns and beams that forms the skeleton of a building and upon which everything else is hung.

Steel is the form of iron most useful as a building material. It differs from cast iron in that it is not brittle, but malleable—that is, it can be shaped by hammering or pressing or rolling. Wrought iron is also malleable, but cannot be manufactured by mass production. It is, therefore, more expensive, less plentiful, and less uniform in quality than steel.

Steel can withstand both compression and stretching; in this respect it may be compared to wood. Long spans are easy in steel construction.

Steel has two great enemies, fire and corrosion. Although steel does not burn, it loses its strength very rapidly in even a small fire. For protection from both fire and rust, the steel frame is surrounded by fireproof material.

Steel is used for many other building purposes: doors, windows, stairs, decking, roofing, gutters, siding, lath, hardware, plumbing, heating, and most other mechanical-equipment items. Cast iron serves for boilers and radiators, as well as for plumbing fixtures and drainpipes.

REINFORCED CONCRETE

Concrete was employed extensively by the Romans and can thus hardly be called a modern material. But when it was discovered in the late 19th century that concrete can be reinforced with steel rods, an entirely new type of material was born. Concrete is as durable as any material known to man, and it is capable of supporting enormous loads. When reinforced with steel, it can be used, like steel, for long spans and light construction.

One of the advantages of concrete is that it is monolithic. It forms a single block. It can be poured into forms, and it hardens in place so that the whole structure is like one massive stone. But this is also a disadvantage, since it requires an enormous amount of material and labor to make the forms into which the concrete is poured. Besides, time is lost waiting for the poured concrete to harden.

Concrete can also be precast into blocks or slabs before they are placed in the building. However, large precast concrete units are very heavy, which makes shipping and handling very expensive.

INSULATING MATERIALS

Insulating materials conserve heat in a building. These are applied first to the heater itself and to the pipes or ducts that lead from it. Then the walls and roofs of buildings are insulated.

Batts of glass insulation are being installed between the studs of a new house. The backing on the batts serves as a vapor barrier, keeping warm air inside.

Owens-Corning Fiberglass Corp.

One popular type of wall and ceiling insulation is a sort of quilt made up of some woollike or cottonlike material glued to a piece of tough building paper or foil, which serves as a vapor barrier. The fibers may also be sandwiched between two layers of paper or foil. Mineral-wool stuffing made from rock, slag, or glass is common. Wood or bark processed into a fibrous, woolly material has been used in the past, as have other natural materials such as eelgrass, kapok, and cotton. The insulation may be sold in large blankets, long rolls, or in precut batts. Occasionally, the filling material in loose form is simply poured or blown into the hollow spaces in walls or between ceiling joists. The loose filler is often mineral wool or vermiculite.

Asbestos, a fibrous rock, was formerly used as insulation in commercial and industrial applications. It was found, however, to be a serious health hazard, particularly to manufacturers and installers, and its use as an insulation was discontinued. Because of the potential injury to health posed by the various fibers, dusts, resins, and adhesives used in the manufacture of most modern insulations, manufacturers recommend that installers wear protective masks and gloves.

Another type of insulating material does double duty. It is made in the form of a building board and can take the place of wood sheathing, lath, or both lath and plaster. These insulating boards are of glass fiberboard, urethane, or polystyrene foam.

All of the insulations that we have mentioned above trap thousands of little pockets of dead air, which, since they cannot move, act as excellent insulators. An insulation that works on an entirely different principle is aluminum foil, which reflects the heat waves in exactly the same way that a mirror reflects light waves.

A great deal of heat is lost through windows and doors, most of it through the cracks around the edges. Weather stripping is applied to stop this loss. Interlocking metal strips are the ordinary form of weather stripping, but felt or rubber gaskets are not uncommon. Heat loss through the glass itself can be reduced only by adding another piece of glass to form an insulating air space between. This is usually done in the form of a storm sash. A double glass, with the air space between permanently sealed, can be installed in any ordinary sash just like a single piece of glass.

SHEET MATERIALS

With the thin, sheetlike materials known as *wallboards*, large areas of wall or ceiling can be covered very quickly, and the wall can be painted immediately afterward. Some waterproof types have been developed for the exterior of buildings.

The first wallboards were made of very heavy cardboard. Next came *plasterboard*, an early sandwich-type board consisting of a thin core of gypsum with faces of heavy paper. Then came the *fiber*, insulating *boards*, mentioned above. Another type, known as *hardboard*, is thin and smooth, and, as the name implies, very hard. It may be made of wood fiber compressed under very heavy pressure, or of asbestos and cement, or of paper impregnated with a synthetic resin. All of these materials may be obtained already decorated. Some of the hardboards have an enamel finish of synthetic resin.

Plywood is a sheet material made up of three or more thin sheets of wood, called *veneers*, glued together with the grain of each sheet at right angles to that of the adjacent sheet. Since the strength of wood is much higher and its shrinkage is much lower along the grain than across the grain, plywood produces a stable board that is strong in any direction.

Plywood was just another wallboard until the middle of the 1930's, when waterproof plywood was developed. This made plywood a dependable, weatherproof building material that could be applied indoors or out, structurally or decoratively.

Most plywood is made of Douglas fir. For decorative effect, plywood can be faced with practically any known wood, including many rare and beautiful imported ones. This has resulted in an increasing use of natural wood as an interior finish.

Corrugated sheet steel has long served for exterior walls and roofs of factories and other utilitarian buildings. Corrugated fiberglass is often used for awnings. These thin materials have sufficient stiffness to span between supports and are economical for enclosing a frame structure.

The development of sheet materials and waterproof adhesives has encouraged a more efficient use of materials in the structural engineering sense. Now we can attach a finishing material to the frame in such a way that both act together as one, and the finishing material actually carries a considerable part of the load. This type of construction is known as *stressed-skin*. Prefabricated stressed-skin panels are usually of plywood, though they may be of steel, aluminum, or fiberboard. The hollow spaces in the panels are filled with some insulating material, such as glass wool.

The *sandwich-type panel* represents an even more advanced step. Imagine a stressed-skin panel of the type we have just described, but with a rigid insulation, like corkboard, instead of glass wool. The faces may then be glued directly to the insulation.

OTHER MODERN MATERIALS

Asphalt served the ancient Babylonians for calking and waterproofing, but modern construction has given it many more jobs. We all know it in paving and in roofing. The commonest modern roofing material is a felt made of paper and asbestos and impregnated with asphalt.

Linoleum is a resilient, sheet flooring material made of linseed oil and ground cork. It is very popular, since it gives an attractive and durable floor that has no cracks and is easy to clean. Other modern flooring materials are rubber, cork, and plastic.

A number of modern materials have become important in building. Aluminum is used for roofing and siding as well as for decorative purposes. Plastics in the form of adhesives and coatings are popular. Extruded and molded plastics are being used in a widening range of applications, from drainage pipes and siding to decorative panels and entire bathtub and shower enclosures.

American Iron and Steel Institute

METALLURGY

by Harry J. Wolf

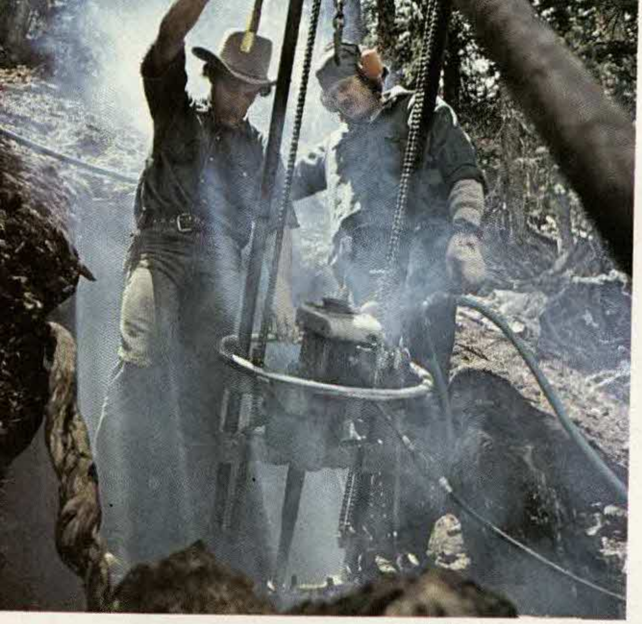
Metallurgy is the science and art of extracting metals from their ores and preparing them for practical and commercial use. It transforms metals from their original state in the earth's crust, where they are mixed with or held by various minerals, into a concentrated or pure condition. Metallurgical processes include the refining of metals and the manufacture of *alloys*, which are mixtures of metals for special purposes.

In metallurgical operations, both chemical and physical principles are applied. Metal-bearing materials are treated on a large scale, with quantities being measured in metric tons. In this respect, the methods of metallurgy differ from those employed in the chemical laboratory, say, where materials of different kinds are investigated on a small scale, usually in grams or even smaller units.

AN ANCIENT TECHNOLOGY

Metallurgy has developed a high state of efficiency during recent years. However, it is not a strictly modern science, since some of its basic principles have been known and employed for many centuries. The art of smelting goes back to the early part of the Age of Metals. Some five thousand years ago, the ancient Egyptians extracted iron from its ores and made it into various utensils. Certain eastern nations knew how to prepare the alloy steel from iron around 500 B.C. The art of extracting other common metals besides iron from their ores has been known for hundreds of years.

Toward the middle of the sixteenth century, Georgius Agricola, or Bauer, a German physician who had become interested in mining and metallurgy, published a



Frank "Shorty" Wilcox/Image Bank

Modern prospecting involves an understanding of crustal movements and volcanism and a detailed knowledge of minerology.

famous book on the processing of metals. This work, called *De Re Metallica* (*Concerning Metals*), deals with mining operations and numerous types of smelting furnaces in considerable detail. Of course, the methods described by Agricola were elementary and crude as compared with our modern procedures. Modern metallurgy has developed methods and equipment that were unknown a hundred years ago.

SERIES OF OPERATIONS

In the sequence of operations by which mineral-bearing rock is transformed into pure metal, the first step is the discovery of an ore body—a rock formation containing ore. Before going further, it would be well to define accurately the word *ore*. Not all mineral-bearing material is ore. Technically speaking, it is ore only if it can be mined at a profit. It must occur in sufficient quantity and have a sufficiently high average value so that the price received for the end product will cover the cost of operations and still yield a reasonable profit.

PROSPECTING

Ore bodies are usually found as a result of the preliminary step known as *prospecting*—the search for or exploration of new ore deposits. It involves a basic knowledge of geology and mineralogy. The prospector must be able to recognize mineral outcrops on the surface and must also be able to tell when there is a strong possibility that mineral deposits are nearby.

The prospector who finds the ore deposit may be able, from his knowledge of mineralogy, to distinguish between the different minerals in the ore and to recognize those of commercial value. However, when the eye or the magnifying glass does not give him enough information regarding the probable value or nature of the mineral, he resorts to the miner's pan. This has a flat, circular bottom surrounded by sloping, rounded sides. A sample of ore, crushed finely enough to separate the valuable minerals from the materials with which they have been mixed, is placed in this pan and water is added. The pan is then shaken back and forth. The buoyancy of the lighter and usually worthless materials causes them to remain at or near the surface, and they are washed over the rim of the pan. The heavier minerals or concentrates, mostly sulfides or oxides and often metallic particles of gold and platinum, remain in the pan. By observing the relative quantities of the heavy and light minerals, the prospector can estimate the approximate value of the ore. He can determine whether it is worthwhile investigating the ore body further.

If the ore deposit happens to be a quartz vein, through which finely divided gold particles are scattered, the concentrate that remains behind after panning is made up of tiny particles of gold. We then have what the miner calls a "string of colors."

The mineral deposit may be of such a nature that the prospector is unable to estimate its probable value by panning. In that case he takes representative samples of minerals for testing by the process called *assaying*. We may consider an *assay* as a miniature metallurgical or chemical operation conducted on a laboratory scale. We describe dry and wet assays later on in this article.

Ore deposits may occur in a great variety of sizes and shapes. They may be in large deposits, which are exposed on the surface and which may be mined with bulldozers, power shovels, and trucks. Sometimes a massive deposit is covered with a layer of soil, called *overburden*. If this is not too thick, it may be removed or stripped by bulldozers, power shovels, or scrapers. The deposits may then be mined by conventional open-pit methods.

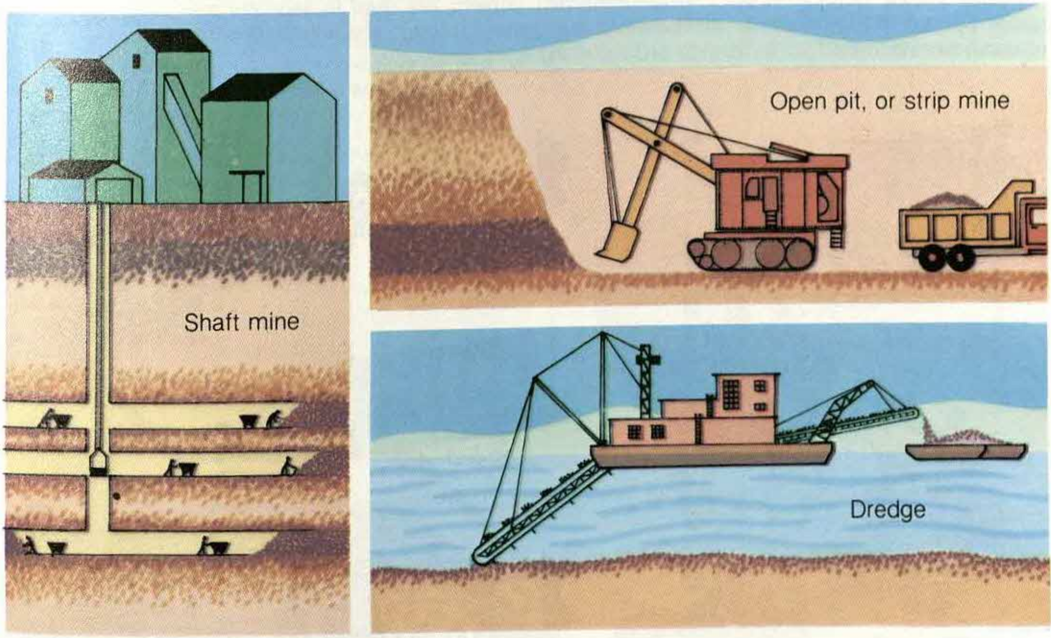
Certain massive deposits are too far below the surface for stripping, or else they are covered by a thick layer of rock. They are developed in various ways. Flat-lying or nearly horizontal deposits may occur as extensive layers, outcropping in the walls of a gulch or canyon which has been exposed by the deep erosion of the earth's surface. Such deposits may be attacked by tunnels driven into the hill or mountain from the outcrop. Other deposits are developed by means of shafts sunk into the ground to the appropriate level.

MILLING AND ORE DRESSING

When the ore from the mine is delivered to the receiving bin at the mill, the process of *ore dressing* begins. This represents the preparation of the ore for subsequent treatment. Its prime object is to separate, by mechanical means, the valuable minerals from the worthless material, called *gangue,* with which it happens to be associated. The valuable product that results from ore dressing is called a *concentrate*. Since it still contains various impurities, it is usually shipped to a smelter so that it may undergo further treatment.

Certain ores which are rich in the desired material may be shipped directly to a smelter without the preliminary preparation accomplished by ore dressing. The ore-dressing process is also eliminated in the case of ores containing ingredients that can serve as *fluxes*. Fluxes are substances that mix with various impurities in the smelting furnace, forming a liquid slag. However, most ores require preliminary treatment to reduce both the volume and the weight of the undesirable minerals. This treatment reduces the costs of transportation and of smelting.

Three basic mining methods. In the shaft mine, a vertical shaft is sunk in the ground, and tunnels lead from the shaft to the deposits. Strip, or open-pit, mining is used to develop deposits located near the surface. In the portal mine, a more or less horizontal tunnel is driven from an outcrop to a mountainside.

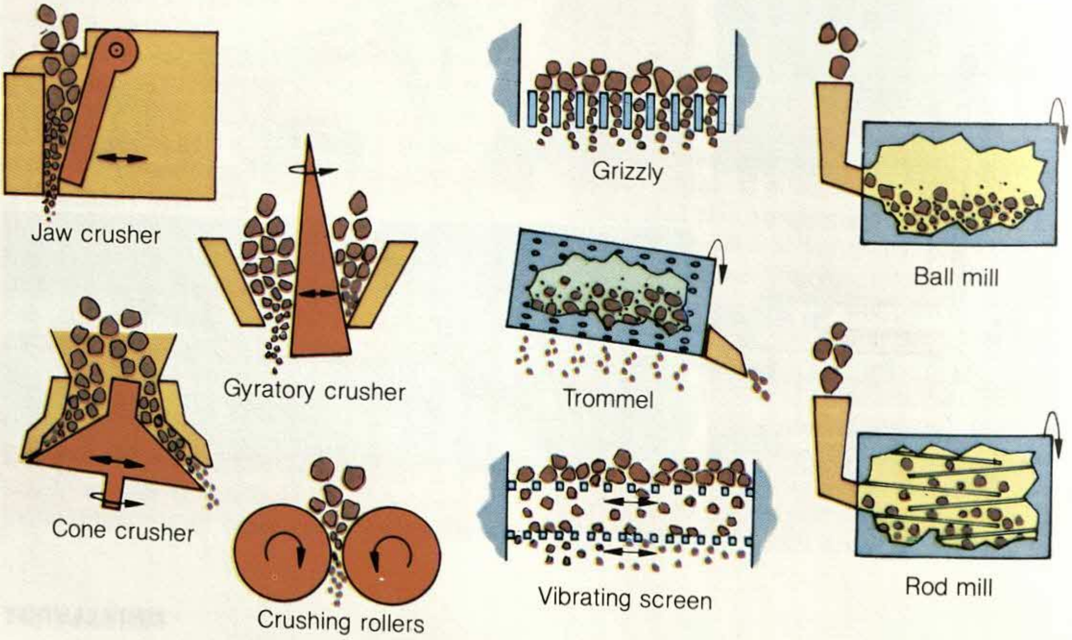

Shaft mine
Open pit, or strip mine
Dredge

Crushing. Ore may come from the mine in a wide range of sizes, from fine dust to chunks of material 30 centimeters in diameter. This variety may result from blasting operations in underground mines. In fact, such operations may be regarded as a preliminary form of crushing.

The ore that is sent to the concentrating mill is first subjected to various crushing devices, including jaw crushers, gyratory crushers, cone crushers, and crushing rolls. A *jaw crusher* is made up of two faces or jaws. One of these is stationary, while the other moves alternately toward and away from the stationary face, crushing the ore between the two faces. The opening through which ore is fed into the jaw crusher is larger than the one from which the processed ore is discharged. This latter opening is adjusted to deliver the desired size of crushed ore.

The *gyratory crusher* is based on a different principle. In this device, the stationary crushing device is a conelike structure open at both ends and with the smaller opening at the bottom. Another cone is placed inside the first. It is quite similar to it, but has the broader part at the bottom. A gyrating, or whirling, motion is imparted to the inner cone. Rock is fed into the device from the top and is crushed between the surfaces of the two cones as the inner one whirls around. *Cone crushers* are modified gyratory crushers. There are also two cones set one within the other, but in this case the narrow parts of both cones are at the top. *Crushing rolls* are made up of two revolving cylinders between which the ore is passed.

Screening. At various stages of the crushing operations, materials have to be separated according to sizes. This is generally done by means of screens. The *grizzly* is the simplest type of screen. It is a stationary device, consisting of parallel bars, or rails, so spaced as to permit material of small size to fall through the openings, while the larger chunks are kept on the rails. Other screens—trommels and vibrating screens—are of the moving type. A *trommel* is a cylindrical shell through which holes have been punched. It revolves about an axis set at a slight angle to the horizontal so that the material to be screened



Pulverizing ore. Left: ore sent to the concentrating mill is subjected to crushers like the ones shown. Middle: in the concentrating mill, screens are used to separate materials by size. Right: the finer ore particles are ground through the tumbling action of metal balls or rods.

will slide from one end of the trommel to the other. The finer materials pass through the holes as the trommel revolves. The coarser pieces are delivered at the end of the device. *Vibrating screens* are set in motion either mechanically or by the action of an electromagnet or an armature. These screens are sometimes set one on top of the other. In this way, products of several sizes can be readily separated.

Grinding. Finer materials are reduced to smaller size by various types of grinders. The grinding operation represents the final pulverizing step before the ore is subjected to various separation processes—gravity concentration, flotation, magnetic separation, and so on—that we describe later. In the machines called *ball mills,* the grinding is done through the tumbling action of steel or iron balls in a steel cylinder or conical drum, which is made to revolve about a horizontal axis. The material to be ground is fed into the mill and is crushed by the tumbling action of the balls. Steel rods are used instead of balls as the grinding medium in the device called the *rod mill.*

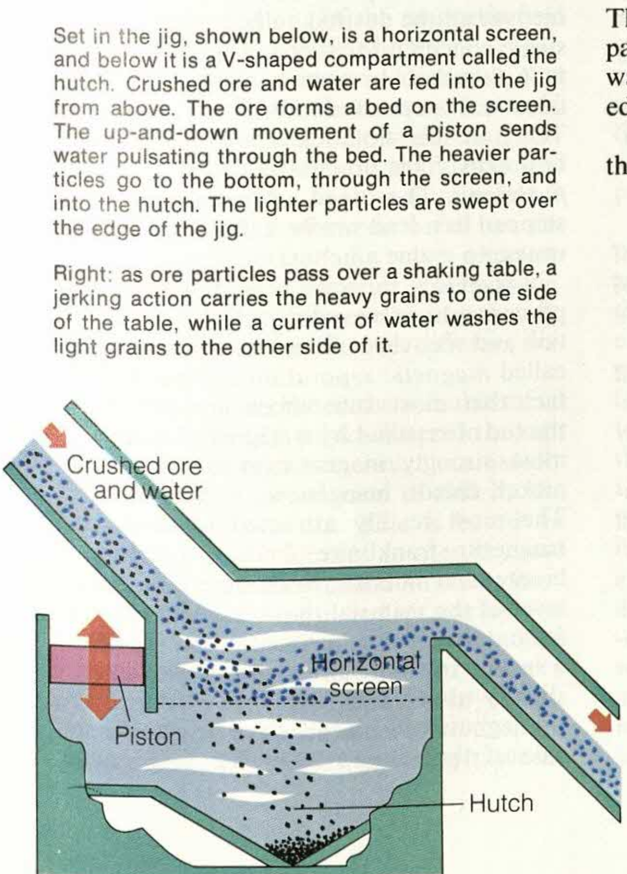
GRAVITY CONCENTRATION

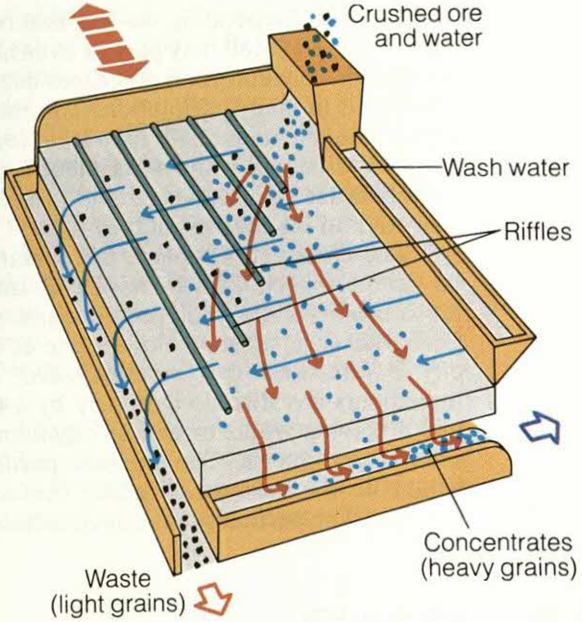
Metal particles are often separated from gangue minerals by what is called *gravity concentration*—that is, a separation through the action of gravity. One of the devices used for this purpose is the *jig*. It is commonly applied to sulfide ores, which have been crushed just enough to free sulfide particles, containing the desired metals, from the gangue minerals that accompany or surround them. The jig is a wooden, rectangular box or tank. Set in it is a horizontal screen, and below the screen a V-shaped compartment called the *hutch.* Crushed ore and a regulated amount of water are fed to the jig from above, and the ore particles form a bed upon the screen. A piston moving to and fro in an adjacent compartment sends a column of water moving through the bed. As the pulsating column passes through, the dense particles work their way to the bottom. They pass through the screen and fall into the hutch. The gangue minerals and the smaller sulfide particles are buoyed up by the pulsating water long enough to be swept over the edge or lip of the jig.

The sulfide minerals that have fallen through the screen into the hutch are drawn

Set in the jig, shown below, is a horizontal screen, and below it is a V-shaped compartment called the hutch. Crushed ore and water are fed into the jig from above. The ore forms a bed on the screen. The up-and-down movement of a piston sends water pulsating through the bed. The heavier particles go to the bottom, through the screen, and into the hutch. The lighter particles are swept over the edge of the jig.

Right: as ore particles pass over a shaking table, a jerking action carries the heavy grains to one side of the table, while a current of water washes the light grains to the other side of it.





off from time to time through a valve. They are accumulated in a storage bin as concentrates. Eventually they are shipped to a smelter. The overflow from the first jig may go to other jigs, called middling jigs or *finishing jigs*. They are designed to remove and recover smaller particles of sulfide mineral than those recovered in the first, or coarse, jig.

After the desired metals have been concentrated by the jigs, the remaining material, which may still contain valuable sulfides, is frequently passed to *shaking tables,* also called *vanners* and *wet concentrating tables*. They are rectangular in shape. Upon the surface of each is fastened a series of parallel cleats, called *riffles,* each longer than the one next above it. A bumping or jerking action is employed to convey the heavy grains to one side or end of the table, while a current of surface water washes the light grains to the other side. This brings about a separation of the concentrates from the gangue material.

Sometimes the jigs are completely eliminated from the separation processes. From the crushers, the ore passes directly to the shaking tables. This happens when the preparatory crushing of the ore does not liberate sulfide particles large enough for efficient treatment in a jig.

RECOVERY

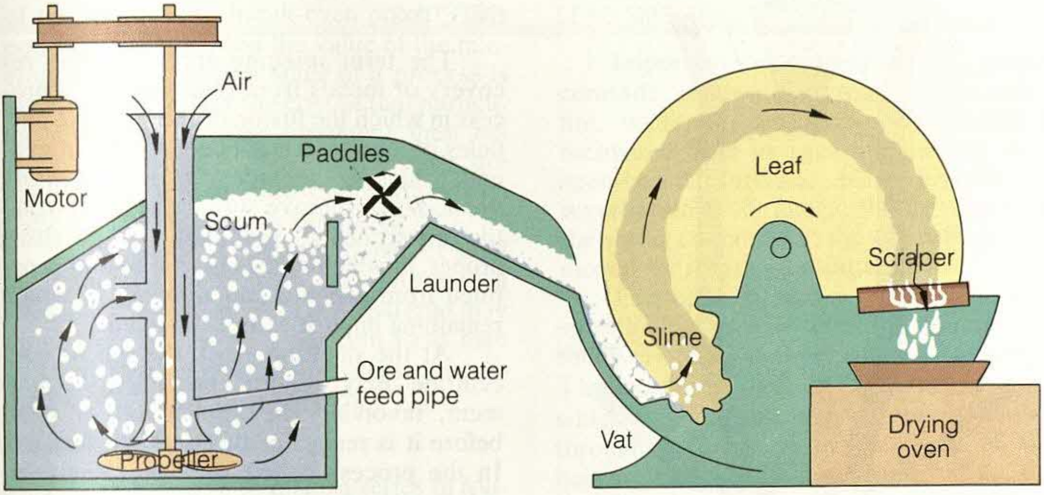
Flotation. Depending on the nature of the ore to be treated, any part or even all of the gravity-concentration processes may be eliminated in favor of flotation. The recovery of valuable minerals by *flotation* (or *oil flotation,* as it was originally called) is possible because mineral fragments of proper size stick to oil-coated bubbles.

The process takes place in a rectangular vat or tank, called a *flotation cell.* Into it are introduced finely divided mineral particles, water, a substance of a more or less oily nature, and certain chemicals. The ingredients are stirred vigorously by a rapidly revolving propeller, and an oily foam or scum is produced. The mineral particles adhere to the bubbles of which the scum consists. The particles that do not adhere to the bubbles sink to the bottom of the cell. As the mineral-bearing foam rises to the surface of the flotation cell, it is scraped off by suitably designed paddles into a trough, called a *launder.*

The launder delivers the slimy product to a tank or vat, provided with a set of canvas-covered filters. These are in the form of hollow disks, called *leaves,* which are made to rotate slowly on a horizontal axis. Only the lower part of the disks are immersed in the mineral-laden slime in the filter tank. As this lower part turns slowly, it is under a vacuum, which causes a layer of the scum to adhere to it. The part of the disk containing the scum then rises above the surface, and the vacuum is automatically replaced by pressure. This causes the layer of slime to fall off the leaf. (Sometimes it is scraped off.) It passes to a drying oven and then to a concentrate storage bin. The dried concentrate is put in sacks or otherwise prepared for shipment to a smelter. Flotation may be carried on in a single cell or in a series of cells, arranged side by side.

A flotation plant may be designed to recover all the desired sulfide minerals in a single concentrate. Such a process is called *bulk flotation.* In certain plants, lead sulfides are separated from zinc sulfides. There are lead-flotation cells and zinc-flotation cells. This process is called *selective flotation.* The lead concentrates are shipped to a lead smelter; the zinc concentrates, to a zinc smelter.

Magnetic separation. Numerous other processes have been devised for the separation and recovery of minerals. The method called *magnetic separation* is based on the fact that most substances are either attracted or repelled by a magnet. Among the most strongly magnetic metals are iron, nickel, cobalt, manganese, and chromium. The most readily attracted minerals are magnetite, franklinite, ilmenite, pyrrhotite, biotite, and siderite. In one method, a thin layer of the material that is to be treated is fed onto a moving horizontal belt. There is a second moving belt, at right angles to and slightly above the first one. Strong electromagnets are placed close to the upper side of the second belt. The magnetized



Recovery of minerals by flotation. Into the tank, or flotation cell, mineral particles are introduced, together with water, an oily substance, and chemicals. The ingredients are mixed by propeller, and an oily foam, or scum is produced. Mineral particles adhere to the foam, forming a slime. The slime is scraped off by paddles into a trough—the launder. The launder delivers the slime to a tank provided with filters in the form of disks, called leaves, rotating on a horizontal axis. As the lower part of the leaf turns in the slime, a layer of the scum adheres to it. This is scraped off and passed to a drying oven.

particles are pulled off the first belt and up against the lower side of the second belt. They are carried out of the magnetic field and then fall into a bin or hopper.

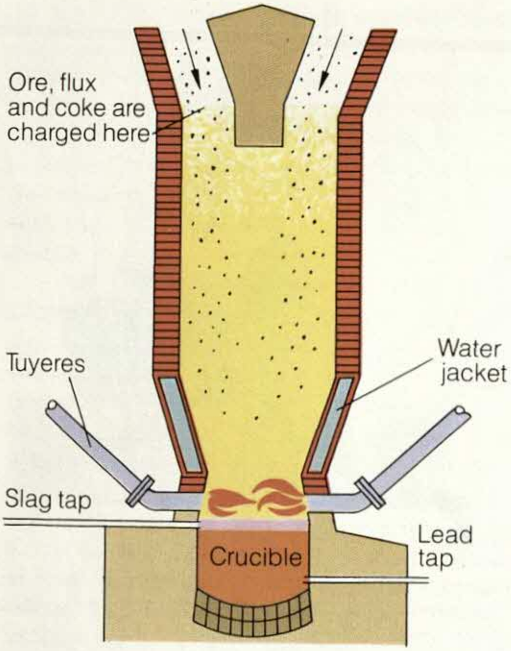
Electrostatic methods. Minerals may also be separated by electrostatic methods, which depend on the fact that different substances respond differently to the action of an electric field. If a mixture of minerals in a neutral state is allowed to fall on the highly charged surface of a rotor, a separation of the different minerals will be made. They will fall into different bins as they fly away from the rotor through different distances.

Amalgamation. When the valuable metal in an ore is mostly gold, scattered through quartz or a similar material, it is usually recovered in a special kind of mill by the *amalgamation process*. This is based on the fact that gold adheres to mercury and forms with it an alloy called an amalgam.

The ore is first crushed by a set of five stamps, forming a *stamp battery*. The stamps are set inside an iron box called a *mortar*. They are raised by cams keyed to a camshaft, and are then allowed to drop on the ore inside the mortar, crushing it. Water is fed into the mortar and forms a thin mud or slush with the crushed ore. As the stamps drop on the ore, the slush is splashed through a screen on the front side of the mortar. The screen is designed to regulate the size of the particles passing through it. Any particles that are too large are held back and subjected again to the pulverizing action of the stamps.

A thin film of mercury is distributed over plates made of amalgamated copper and set at an angle. After passing through the screen of the mortar, the slush flows in a thin layer over the mercury film of the plates. The gold particles in the slush then form an amalgam with the mercury. At intervals, the gold amalgam is scraped from the plate and is squeezed with a chamois skin to remove the excess mercury. The amalgam is then placed in a cast-iron crucible and the mercury is distilled off, leaving a sponge of gold. The mercury is recovered and is used again in the amalgamation process.

The gold sponge is placed in a graphite crucible with one of the common fluxes, such as borax, soda, or silica, and subjected to intense heat. The flux fuses with any im-



The lead blast furnace has tapering sides, a water-jacketed smelting zone, and an internal crucible to hold the molten metal. The furnace is charged from the top with ore, flux, and coke (the fuel). A high degree of heat is maintained by blasts of air through tuyères. Slag and molten lead are drawn off at intervals. Matte and sometimes speiss are also formed and drawn off.

purities in the sponge and carries them off in the form of slag. The molten gold is poured into iron molds and is formed into bricks.

Cyanide process. Another process that is widely used for the recovery of gold from its ores is the *cyanide process*. It is applied to ores free from sulfide minerals and to pulp from which the sulfides have been removed in a concentrating mill. In this process, the gold is dissolved in a solution of potassium or sodium cyanide. The solution containing the gold is allowed to flow through boxes or vats containing trays of zinc shavings. The cyanide combines with the zinc. The gold, in the form of sludge, falls to the bottom of the vat. It is flushed out by water, filtered, precipitated, and dried. Eventually it is smelted. Sometimes the zinc shavings are replaced by zinc dust. A cyanide plant is often set up next to a gravity-concentration mill.

SMELTING

The term *smelting* applies to the recovery of metals from their ores by a process in which the fusion of the separate particles of a given metal plays a part. In general, smelting includes various *heating processes* to remove sulfur and other volatile constituents; reduction, or smelting proper, in which metals are fused and separated from gangue; and *refining*, in which remaining impurities are removed.

At the smelting plant, the ore or concentrate may require preliminary treatment, involving the application of heat, before it is ready for the smelting furnace. In the process called *sintering*, finely divided ore is partly fused, forming *clinkers*, as heat is applied. Thus it is made more suitable for later treatment. The process of roasting has several stages. The first stage is *drying*—that is, expelling any water that is not chemically combined with the ore. This is usually accomplished when the temperature reaches 100° Celsius. A further rise in temperature drives off the chemically combined water, as well as volatile carbon-containing material. Carbonic acid is expelled from carbonates. This stage of the process is called *calcination*. As the temperature rises still higher, the ore is attacked by the oxygen in the air, and oxides and sulfides of the meatals are formed.

Before we consider smelting processes as applied to various metals, let us point out that metallurgy or, more particularly, smelting is divided into two broad classifications—ferrous and nonferrous. *Ferrous metallurgy* applies to the recovery of iron from its ores and to the making of steel, which is an alloy of iron. *Nonferrous metallurgy* is concerned with the recovery of common metals other than iron—metals such as copper, lead, and zinc. The smelting processes involving iron and its alloy steel are considered in the article "Steel" in *The New Book of Popular Science*. We shall discuss here the smelting of a few important nonferrous metals.

THE POINT OF NO RETURN

In any or all of the processes we have described, there is what is called the "point of no return," or "break-even point." This point is reached when the value of the mineral recovered at any stage of a process is insufficient to cover the cost of that particular recovery. Further treatment then becomes unprofitable. No other efforts are made to extract any more concentrate from the ore. The material is discarded.

It is usually impossible to extract all of the mineral values in an ore. The milling losses in the treatment of any material may range from as low as 2 per cent to as high as 15 percent or even 20 per cent, depending on the "point of no return."

ROUTINE ANALYSES

It is customary to make a series of routine analyses of the metal content and the value of the materials handled in the different stages of mining and milling. Materials are usually analyzed by the dry assay or by the wet assay.

In the dry, or fire assay for ores of the precious metals, an ore sample is mixed with fluxes and lead and then put into a crucible, which is heated in a furnace. The impurities in the ore form a slag with the fluxes.

The precious metals (there are generally more than one in a given sample) combine with the lead, forming what is called *button*. The button is heated in a container known as a *cupel*, and the lead is changed to lead oxide as it combines with oxygen. The precious metals that have been freed from the lead are treated with acids so that they can be separated from one another. They are then weighed to indicate the precious-metal content in the original sample.

The dry assay is sometimes applied to base metals, but only when extreme accuracy is not required. For accurate determinations, the wet assay is used. This consists of a series of chemical analyses.

Products which are to be shipped to a smelter, either as mill concentrates or as crude ore from the mine, are assayed as a check against the analysis made at the smelter. The smelter people assay each lot of material as soon as it is received, as a basis for payment to the shipper.

LEAD SMELTING

Important lead ores include galena, cerussite, anglesite, pyromorphite, mimetite, wulfenite, and jamesonite. Lead is recovered from its ores by smelting in an open-hearth furnace, blast furnace, or reverberatory furnace. Before smelting, the sulfur contained in the ore is largely removed by roasting or sintering.

The open hearth is used mostly to smelt high-grade concentrates, containing a relatively small amount of other minerals. The hearth is shallow. The fuel is coke, which is kept blazing as air is blown through tuyères set in the back of the hearth. The concentrates are fed to the hearth and are reduced in large measure to lead. The lead forms a molten mass at the bottom of the hearth. The molten slag residue floats on top. Both the lead and the slag are drawn off at intervals. The slag may contain a considerable amount of lead. It is usually sent to the blast furnace for further processing to obtain this metal.

The lead blast furnace treats not only the slag from the open hearth but also low-

An open-pit copper mine. Sulfide ores of copper are the most important. Copper is used in wire, among other things.

Hetier

Joseph B. Brignolo/Image Bank

Operators work in the safety of a control room in a steel mill.

grade mill concentrates and high-grade concentrates containing a considerable quantity of metallic impurities. It is a shaft furnace, with tapering sides. It has a water-jacketed smelting zone and an internal crucible to hold the molten lead. The furnace is charged from the top with a mixture of ore, fluxing materials, and coke, which serves as the fuel. A high degree of heat is maintained by blasts of air from tuyères. The molten lead sinks to the bottom of the furnace crucible, where it is drawn off. The lighter slag floats on top. Between the slag and lead, a matte develops—a sulfide containing gold, silver, lead, and copper. If arsenic and antimony are present in the furnace charge, a substance called *speiss* is also formed. It is lighter than the lead but heavier than the matte and it forms a molten layer between them. Speiss acts as a collector of other metals such as nickel and cobalt.

The molten lead from the furnace is transferred to a so-called *drossing kettle,* where it is freed from impurities. It is then converted into bullion. The matte and speiss are specially treated in order to recover the metals they contain.

The reverberatory furnace serves mainly to smelt lead scrap and byproduct material. This furnace is a long brick hearth with a low, arched roof. The source of heat is at one end and there is a flue at the other. Lead and fluxes are charged in the hearth where the smelting takes place. The products include metallic lead and slag.

After lead has been processed by smelting, it still contains small quantities of other metals—gold, silver, platinum, copper, zinc, bismuth, antimony, iron, nickel, and cobalt—and also of nonmetals such as sulfur and arsenic. The lead is refined to remove these "impurities" and is then converted into ingots, which are not less than 99.7 per cent pure. Many of the impurities are recovered by various methods of treatment and are made into various kinds of salable products.

ZINC

Among important zinc ores are sphalerite, smithsonite, calamine, zincite, willemite, and franklinite. In recent years, since the efficient development of selective flotation, zinc-bearing flotation concentrate may have a zinc content as high as 50 per cent. Hence much of the zinc processed in zinc smelters is now in the form of flotation concentrate.

The preliminary treatment stages include sintering and roasting. After these stages, however, zinc metallurgy differs widely from that of either copper or lead. No blast furnaces are used. In one method, the zinc is distilled in furnaces, consisting of banks of retorts made of clay or car-

American Iron and Steel Institute

A soaked ingot is being withdrawn from a pit by remote control.

borundum and provided with condensers. After the gas that serves as fuel is turned on in the furnace, a period of about two hours is required for the preliminary reactions. The fumes in the condensers become purple and then show tinges of green from the burning zinc. In the condensers, the zinc vapor is condensed into liquid form and is drawn off at intervals. The distilling is generally performed in a cycle of 24 hours, although sometimes a 48-hour cycle is adopted. The zinc recovered from the condenser is called *spelter*. It accounts for about 75 per cent of the total quantity of zinc recovered. The rest is in the form of "blue powder," or zinc dust. In efficient operations, 90 per cent of the zinc contained in the concentrates is recovered. The spelter is refined by removal of the lead and cadmium it contains.

Zinc is also extracted from its ores by the *electrolytic-zinc process*, a later development. In this, the zinc ores are first leached in dilute sulfuric acid. The zinc is then obtained in the metallic state by the electrolysis of the resulting solution. Zinc

COPPER

There are three general types of copper ores: *native copper ores, oxide ores,* and *sulfide ores*. The principal oxides are malachite, aurite, cuprite, atacamite, and brochantite. The sulfides are the most important from the standpoint of world supply. They include chalcocite, chalcopyrite, covellite, bornite, and copper-bearing pyrite.

During the smelting of copper-sulfide ores, the products called *slag* and *matte* are formed. Slag is produced by the gangue of the ore and the flux that is added to it. Matte results from the fusion of the metallic sulfides. The object of the smelting process is to make the slag as worthless as possible, liquid enough to flow freely, and light enough so that it may easily be separated from the matte.

The blast furnace formerly played a very important part in copper metallurgy. Nowadays this type of furnace serves principally for working up refinery slags or for other secondary materials. The modern copper blast furnace consists of a water-jacketed rectangular shaft, which is about 13 meters high, 5 to 15 meters long, and about $1^1/_2$ meters wide. The furnace is provided with tuyères, or nozzles, through which air can be blown. The charge of the furnace consists of ore, fuel, and a flux. As the charge melts down in the furnace, the slag and matte, both in molten form, are separated. The slag is lighter than the matte and floats on top of it. The slag is discarded. The matte is drawn off and passes into ladles. These carry it to a copper converter, described on the following page.

The *reverberatory furnace* used in copper smelting serves for the finer ores and also for flotation concentrates. These concentrates have made up the major portion of the smelter's intake in recent years. The reverberatory furnace is so called because heat is reflected from the roof onto the material that is being treated. The furnace consists of a horizontally disposed hearth, which is sometimes 15 meters long by 3 meters wide. The ore and flux are placed in the furnace and subjected to the action of flames from an adjacent fuel-combustion chamber. The material to be heated does not come in contact with the fuel, as is the case with the blast furnace. In the reverberatory furnace, the matte and slag are separated and drawn off in much the same way as in the blast furnace.

The molten matte, whether derived from the blast furnace or reverberatory furnace, passes to the converter. In this vessel, iron and sulfur are removed as streams of air are forced through the liquid mass. The iron and sulfur in the matte are oxidized, leaving molten copper plus certain impurities (which may include gold and silver). At this stage, the molten copper is called *blister copper*. It is sent to the refinery for further treatment.

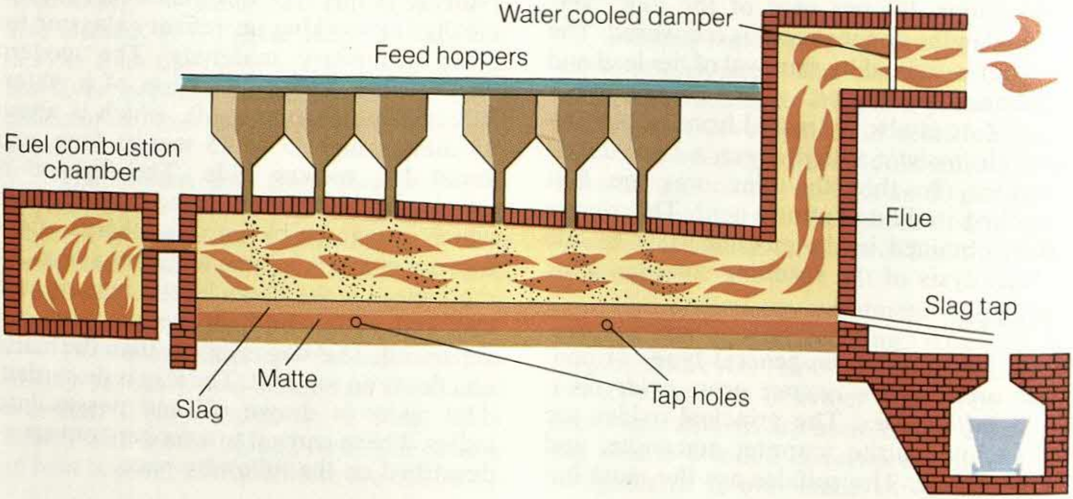
Blister copper is now refined almost entirely by the electrolytic process. It is first subjected to heat as a preliminary step in removing impurities. The copper is then cast into anodes (positive poles) in the form of flat, rectangular plates. It is now ready for the electrolytic tank, containing the solution through which an electric current will be passed. Hooks or ears are cast in the two upper corners of the anode so that it may be properly suspended in the solution tank. As electric current is applied, the anode is gradually dissolved and pure copper is deposited on the opposite electric pole, the cathode. Any precious metals that were contained in the anode are collected as slime or sludge in the bottom of the tank. They are recovered by subsequent treatment.

The cathode copper is cast into forms suitable for commercial use: wire bars, wedge bars, cakes, slabs, and billets for rolling and wire drawing; ingots and ingot bars for remelting.

ALUMINUM

Aluminum is the most abundant element on the face of the earth, making up about 8 per cent by weight of the outer part of the earth's crust. It is never found free in

The reverberatory furnace used in copper smelting consists of a horizontal hearth. Ore and flux are placed in it and are subjected to the action of flames from an adjacent fuel chamber. Heat is reflected from the roof of the furnace onto the ore and flux. Matte, which is valuable mineral matter, and slag are formed and drawn off.



nature but is always combined chemically with oxygen plus other elements. There is only one ore—bauxite—from which it can be extracted in substantial quantities commercially, at least up to the present time. Bauxite is found in France, Surinam, British Guiana, Hungary, and Italy, among other places.

The first step in the production of aluminum is the preparation of pure alumina, or aluminum oxide ($Al_2 0_3$), from bauxite. The bauxite is treated with sodium hydroxide, yielding sodium aluminate. As this cools in precipitating tanks, aluminum hydroxide is formed. Alumina is then obtained by *calcination*.

The best-known process for the reduction of aluminum from alumina involves the electrolytic decomposition of alumina. This is called the Hall-Héroult process. It was discovered independently by the U.S. scientist Charles M. Hall and the French scientist Paul-Louis-Toussaint Héroult in 1886. The alumina is dissolved in a bath of molten cryolite, which is kept at a temperature of about 1,000° Celsius. The molten bath, or electrolyte, is contained in a *cell*—a rectangular box of steel with a double lining. The lining next to the steel is a poor conductor of heat and electricity. On the inner side of this lining, there is a heavier one of carbon, which serves as a cathode in the electrolytic reaction. A set of carbon anodes is suspended in the bath. When current is passed through the electrolyte, alumina is converted into molten aluminum and oxygen. The aluminum, being heavier than the cryolite, sinks to the bottom of the cell. The oxygen is deposited on the carbon anodes, which are gradually consumed. The liquid aluminum is drawn off through a tap hole in the side of the furnace. Practically no change takes place in the cryolite during the electrolytic operation. Alumina is stirred into the bath at intervals in order to keep the operation going. It takes something like 25 kilowatts of electricity to produce a single kilogram of aluminum. Hence cheap electric power is required. Most aluminum reduction works are located near large hydroelectric developments.

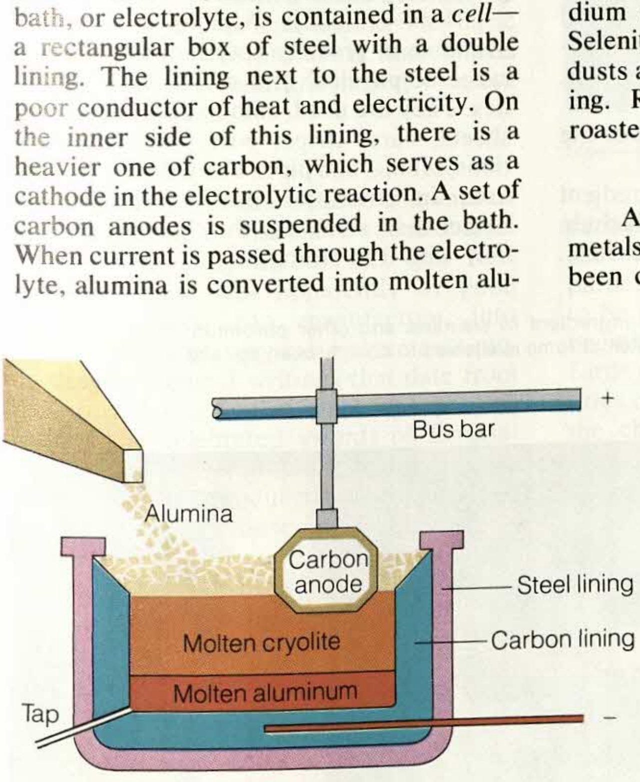
OTHER METALS

Many important metals, other than those mentioned above, are recovered from their ores by metallurgical processes.

Numerous minor metals, which are important commercially, are recovered as metallurgical by-products during the reduction of various major metals. By way of example, cadmium, germanium, and indium are byproducts of zinc metallurgy. Selenium and tellurium are found in flue dusts and in the slimes of electrolytic refining. Rhenium is found in molybdenum roaster dusts.

ALLOYS

An *alloy* is an intimate mixture of metals, or of metals and nonmetals. It has been defined as "a substance having me-



Aluminum is derived from alumina by the Hall-Héroult process, which involves electrolytic decomposition. The alumina is dissolved in a bath of molten cryolite contained in a cell, which is a steel box with a double lining. The inner lining is made of carbon and serves as a cathode, or negative electrode. A set of carbon anodes, or positive electrodes, is suspended in the bath. When electric current is passed through it, alumina is converted into molten aluminum and oxygen. The oxygen is deposited on the carbon anodes, which are gradually consumed. Aluminum is heavier than cryolite. Consequently it sinks to the bottom and is drawn off.

tallic properties, consisting of two or more metallic elements or of metallic and nonmetallic elements, which are miscible with each other [that is, which can be mixed with each other] when molten, and have not separated into distinct layers when solid."

Almost all commercial metal products are alloys. Metals are seldom used commercially in the pure state. Steel, for example, is an alloy of iron, carbon, and other elements. There are thousands of different kinds of steel. Brass is an alloy of copper and zinc; bronze, an alloy of copper and tin; German silver, an alloy of copper, zinc, and other metals; Monel metal, an alloy of nickel, copper, and other elements. There are also alloys of precious metals. White gold is gold alloyed with 25 per cent nickel and zinc, making it look like platinum. Sterling silver is an alloy of silver and other metals, with silver making up 92.5 per cent.

The metal that makes up the chief part of an alloy is called the *basic component*. Iron is the basic component of steel. Copper is the basic component of cupro-nickel, which consists of 70 per cent copper.

Alloys can be divided into ferrous and nonferrous types. Iron is the basic component of ferrous alloys. In nonferrous alloys, the basic component is any other metal. Here we shall touch briefly on some of the important nonferrous alloys.

Copper alloys. Copper is an ingredient in many important alloys. These include aluminum bronze, manganese bronze, typewriter metal, nickel silver, gun metal, cartridge brass, pewter, German silver, hard and soft solders, and many other products. The copper content in these alloys ranges from 50 per cent to 90 per cent. Copper is also used as an alloying element added to other metals. It increases corrosion resistance appreciably.

Lead alloys. Lead alloys are numerous and important. They include type metal, linotype metal, engraving plates, pewter, cable sheathing, white metal, battery plates, and lead foil. The lead content ranges from 18 per cent to 99.8 per cent. Lead is an important ingredient in special solders used to solder lead, zinc, copper, and brass. It also serves in certain alloys with the low melting point. These serve in fuses and automatic-sprinkler systems.

Zinc alloys. Zinc is an important ingredient in a great many alloys, including aluminum solders, fusible solders, white solders, zinc babbit, and battery plates. It forms many alloys with copper, lead, tin and nickel. It is also widely employed in galvanizing ferrous metals.

Aluminum alloys. Aluminum alloys are available in great variety and have a wide range of physical and mechanical properties. They are used, among other things, for sheets, bars, strips, wire, structural sections, tubing, and pipe. The aluminum alloys used in structural members are much lighter than steel, yet they compare favorably with it in strength.

Ferrochrome plant. Chrome, an essential ingredient in stainless and other chromium steels, is tapped from this smelter. The molten chrome is allowed to cool, broken up, and shipped.

Union Carbide

STEEL

The story of steel—an alloy with an iron base—is in large part the story of our technological progress. Out of the molten metal that flows from the furnaces where steel is made come imposing bridges, lofty towers, ocean liners, electrical equipment, farm tools, home equipment, food containers, and a vast number of other products. The world production of steel comes to many hundreds of thousands of metric tons per year. The United States, the Soviet Union, and Japan produce a substantial part of the total tonnage.

Steel is one of the most versatile of materials. It can be made hard enough to cut glass, or pliable enough to serve as a paper clip or the sheet metal used for tin cans. Steel can be made resilient, for the springs of automobiles or typewriters, or rigid, for the wheels of railway cars. It can be drawn into wire a hundredth of a centimeter thick or fabricated into giant girders for bridges and buildings. It can be made resistant to heat, rust, and chemical attack. The basic materials from which steel is made—iron ore, bituminous coal, and limestone—are relatively abundant.

EARLY HISTORY

Modern historians believe that various Asian civilizations knew how to make steel from iron as early as 500 B.C. The steel made in India was apparently of good enough quality for manufacture into various kinds of surgical instruments, according to medical writings that date from 400 to 300 B.C. Indian steel was used to fashion the celebrated swords of Damascus, in ancient Syria.

Steel was produced in exceedingly small quantities in those days. The most important metal then and for many centuries thereafter was iron. It is not known how long ago man first learned to extract iron from its ore. This discovery must have been made long before 1300 B.C. , since in that period objects of iron were made, some of which have survived.

Werner Muller, Peter Arnold

Steel—the skeletal material of modern construction.

Throughout the Greek and Roman periods and for most of the Middle Ages, the malleable iron called *wrought iron* was particularly important. *Cast iron* also came to be manufactured in quantity in Europe beginning with the fourteenth century A.D. Little progress in the refining of large quantities of iron into steel could be made until the chemical nature of steel was understood. In 1781, the Swedish chemist Torbern Olof Bergman made one of the earliest attempts to analyze steel scientifically. He defined wrought iron, cast iron, and steel in terms of the amount of carbon that each contained.

THREE IRON ALLOYS

Today we know that wrought iron, cast iron, and steel are all mixtures of carbon and iron (plus other substances) and that the carbon is chiefly responsible for their strength. Wrought iron is low in carbon content, containing less than 0.2 per cent. It is the softest of the three alloys. It can be hammered and twisted into a variety of shapes, which accounts for its name. Cast iron is much harder, although it is relatively brittle. This is because of its high carbon content of 2.0 to 4.5 per cent. For centuries this alloy has been molded, or cast, into useful forms. The carbon content of steel lies between these two extremes. It is generally less than 1.2 per cent. Steel possesses some of the malleability of wrought iron and is stronger than cast iron.

Even after the nature of steel was roughly understood, manufacturers continued to produce it only in small amounts. Steel began to be used widely in the 1850s with the invention of the *Bessemer process*, which made steel available in far greater quantities than before. Bessemer steel provided much of the metal used for the early railroads and the first skyscrapers. The *open-hearth process*, introduced in the 1860s, was the next important development. The twentieth century saw the introduction of the *electric furnace, oxygen,* and *vacuum processes* of making steel.

IRON—THE RAW MATERIAL

Iron, the chief raw material of steel, is the fourth most abundant element in the earth, exceeded only by oxygen, silicon, and aluminum. Iron very rarely occurs in nature as a pure metal. Nearly always, it is chemically imprisoned in compounds that it forms with other elements.

Most iron-ore minerals are oxides, or compounds of oxygen and iron. The most important of these minerals are *hematite, limonite,* and *magnetite*. Hematite is a common reddish ore. In its pure state it is 70 per cent iron. Pure limonite contains about 60 per cent iron. Magnetite is a black magnetic oxide, with an iron content of 72.4 per cent.

Iron ores also contain minerals that are considered impurities. Most abundant are silica and clay. *Taconite* is an iron ore consisting of iron oxides embedded in silica minerals. This makes it harder to process.

AN ABUNDANT ORE

Great quantities of iron ore are mined in the Americas. In the United States, the chief source of supply for the steel industry is the Lake Superior district, in the states of Minnesota, Michigan, and Wisconsin. The mines of the Mesabi range, in Minnesota, are outstanding. Most of the iron used in U.S. steel mills comes from the Lake Superior district. There are also important iron-ore resources in Alabama, New York, Texas, Wyoming, and other states.

Phenomenally rich deposits have been discovered near the Labrador-Quebec border, in Canada. Other deposits are found in Canada's Lake Superior region. There are vast iron ore resources in the state of Minas Gerais, in Brazil, and in the mountain called Cerro Bolivar, in Venezuela.

The iron mines of Luxembourg and Alsace-Lorraine are among the most productive in Europe. A great deal of ore is mined in northern Spain and Sweden. The iron-ore deposits of the Soviet Union are widely distributed in both the European and Asian sections of the country. India has great iron-ore resources. So have China and the Philippines. Iron ore is mined in northern Africa. There are large reserves in the Union of South Africa. All in all, there is no scarcity of iron in the crust of the earth.

Where iron ore lies near the earth's surface, it is generally scooped up by giant, electrically operated shovels and dumped into railway cars or trucks. This is called *open-pit mining*. Most of the ore mined in the United States today is extracted by this method. Where the ore is too far below the earth's surface, *underground mining* is undertaken.

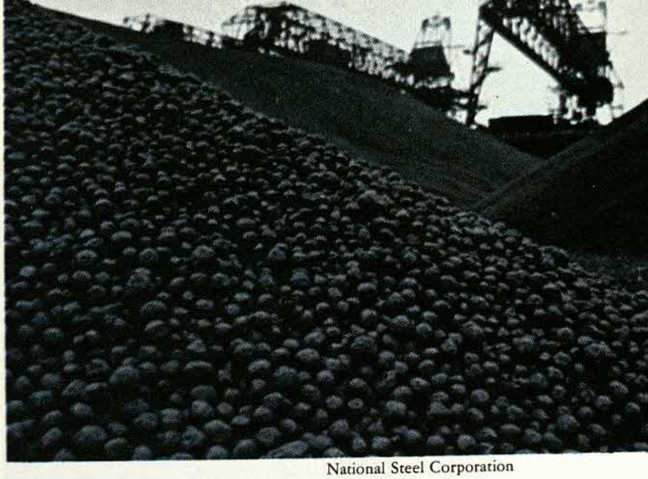
SMELTING

To release iron from its chemical prison of ore, it must be smelted in the blast furnace. Two materials are essential in the smelting process—*coke* (derived from bituminous coal) and *limestone*. In the furnace, the coke generates heat and gases that reduce the iron from its ore and melt it. As this takes place, the iron picks up carbon from the coke. Limestone serves as a *flux*—that is, it fuses with various impurities in the iron ore and carries them off in the form of *slag*.

The coke that is used in the blast furnace is prepared from coal in ovens. Here volatile substances in the coal are vaporized and driven off, leaving behind a gray substance—coke—that is about 90 per cent carbon. This process is called *coking*. Originally coking was done in *beehive ovens*, so called because they resembled beehives in shape. Coal was charged through openings in the roof of the ovens. As the coal was heated, volatile gases were given off. These were ignited and escaped through the opening in the roof. When chemists began to extract valuable by-products from the gases given off in coking, the so-called *by-product ovens* were developed. Coal is transformed into coke in these ovens, and the volatile products of the heated coal are piped into a chemical plant. Here they are treated to yield coal tar, ammonia liquor, and other valuable substances. They have almost entirely replaced beehive ovens.

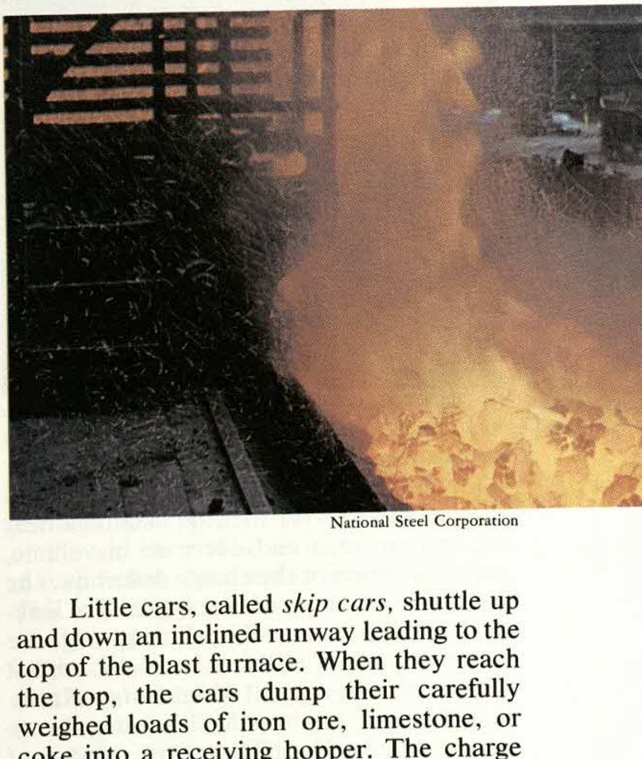
The limestone that is used in the blast furnace is generally extracted from quarries that are in effect open-pit mines. Limestone is crushed at the quarries to uniform lump sizes. Then it is screened and washed. Great care is taken to eliminate any clay.

Today's blast furnace is a tapering cylinder of steel, over 30 meters tall, with a thick lining of heat-resistant brick. Each furnace is connected to three or four dome-topped stoves. These are cylindrical towers, filled with a checkerwork of heat-resisting brick. The brickwork is heated by burning gases. Air is then blown through the stoves, picking up heat from the bricks. The air, reaching a temperature of up to 1,100° Celsius, is driven into the bottom of the blast furnace at a speed of from 320 to 480 kilometers per hour through a set of evenly spaced nozzles, called *tuyeres*. The blast of hot air accounts for the name "blast furnace." In some modern blast furnaces, fuels such as natural gas, oil, and pulverized coal are enriched with oxygen and injected at the tuyeres.



National Steel Corporation

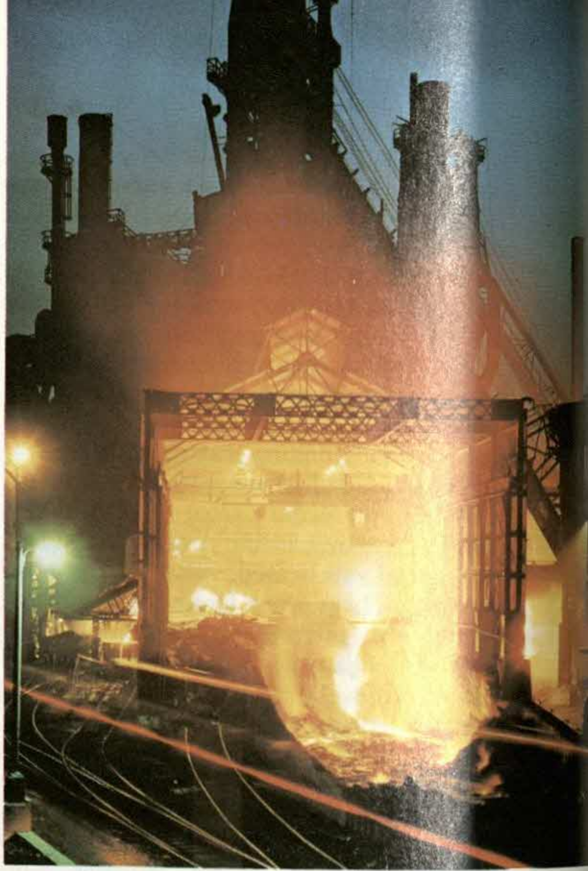
Top: iron that will be used in the manufacture of steel is often stored in pellet form. Bottom: coke ovens are used to prepare the coke that will be used together with limestone in the process of smelting iron ore.



National Steel Corporation

Little cars, called *skip cars*, shuttle up and down an inclined runway leading to the top of the blast furnace. When they reach the top, the cars dump their carefully weighed loads of iron ore, limestone, or coke into a receiving hopper. The charge falls into the furnace through two devices that are called *bells*—a small one above, a larger one below. These are arranged so as to prevent the escape of heat and gases from the furnace. As the coke comes in contact with the blast of hot air from the stoves, it burns fiercely. It produces hot carbon-monoxide gas, in which the iron ore

Right: molten iron is produced in the blast furnace. Here, the molten iron is being tapped from the furnace. Below: molten iron from the blast furnace is being used to charge an oxygen, or LD, furnace. The oxygen furnace is similar to the older Bessemer converter, but, since pure oxygen is used to drive out impurities, the steel is of high quality.



both photos, Republic Steel Corporation

is bathed. The resulting chemical reaction causes the ore to lose much of its oxygen.

The furnace is hotter at the bottom than at the top. As the raw materials near the bottom melt and decrease in volume, the entire mass of the charge descends. The iron ore loses more of its oxygen. The limestone begins to crumble. Fusing with the sandy impurities of the ore and the ash left by the burning coke, it forms a *slag*. At the very base of the hearth, the materials are completely melted. They form a pool of molten iron, on which liquid slag floats.

A blast furnace works continuously, producing up to 2,700 metric tons of iron per day. It runs until repairs are needed or until the demand for the output falls off. Every four or five hours the furnace is tapped. The molten iron gushes out from a tap hole and flows down a trough into a huge container, called a *ladle*. Some ladles have flat, open tops and hold from 35 to 45 metric tons of iron. Others are cylindrical, with a small opening on top. They have a capacity of 150 to 180 metric tons. The ladles keep the iron in a molten condition while it is being delivered to the steelmaking departments.

Sometimes the molten iron is poured from the ladles into a series of molds mounted on a slowly moving chain. In the molds, the iron solidifies into rectangular lumps, called *pigs*, weighing from 20 to 45 kilograms each. These lumps account for the name *pig iron*, applied to iron smelted in a blast furnace. Pigs are sold to steel mills that do not process their own iron and to foundries that manufacture cast-iron products, such as bathtubs and automobile cylinder blocks.

The slag is run off from a separate hole, called the *cinder notch*, and flows down a trough into a ladle. Slag is used in the manufacture of cement and wallboard and is made into mineral wool for insulation material. Other waste products are also put to use. Valuable iron oxide and potash are recovered from the dust in the gases generated in the blast furnace. The gases themselves are cleaned and piped back as fuel to heat the stoves. Automated control of blast furnaces with computers permits the automatic feeding of raw materials. This increases the efficiency of blast furnaces.

MAKING STEEL

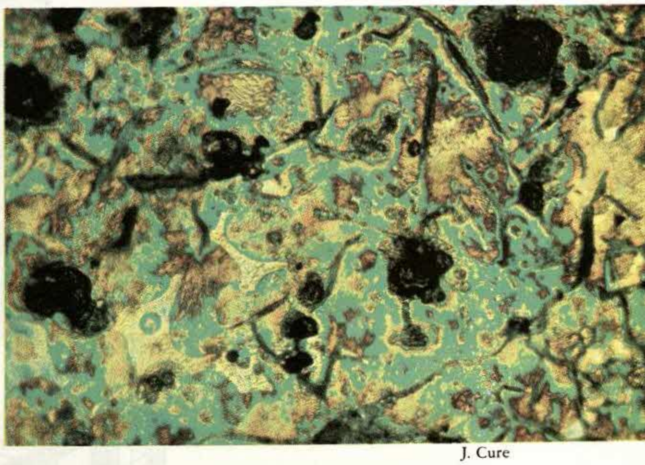
About 90 per cent of the iron smelted in the blast furnace is destined for the steelmaking operation. This iron is by no means pure. It has absorbed from 3.5 to 4.5 per cent carbon from the coke used in the blast furnace. It also still contains some of the impurities present in the iron ore, such as manganese, silicon, phosphorus, and sulfur. To be converted into steel, it must be refined by one of the steelmaking processes: *Bessemer, open-hearth, electric-furnace, oxygen-furnace,* and *vacuum.*

BESSEMER PROCESS

The Bessemer process of steelmaking was discovered independently and almost simultaneously by a U.S. citizen, William Kelly, and a British subject, Henry Bessemer, in the 1850s. Bessemer steel is made by blowing air through molten iron in a *converter*—a pear-shaped, tilting container made of steel plates and lined with heat-resisting bricks and clay. The converter is open at the top and has a double bottom. The space between the upper and the lower parts of the double bottom forms an air chamber, known as the *wind box.* The top of this air chamber is perforated with a number of holes.

The converter is tilted on its side in order to receive a charge of molten pig iron. Then, as the converter is returned to the vertical position, air is blown into the wind box at a pressure of from 1.5 to 2 kilograms per square centimeter and at the rate of 775 to 850 cubic meters per minute. The air pressure is sufficient to keep the molten iron from making its way through the holes at the top part of the wind box. It also serves to force streams of air through the metal bath.

When the air blast is turned on, a shower of sparks bursts from the mouth of the converter. Short, ruddy flames appear, accompanied by brown fumes, marking the early burning of manganese and silicon. The color of the flame rapidly changes to yellow, as the silicon burns away. After the silicon has been oxidized, the flame turns a brilliant white, marking the combustion of carbon. When the flame dies down, the converter is tilted and the steel is poured into a ladle. The entire operation takes from fifteen to twenty minutes.



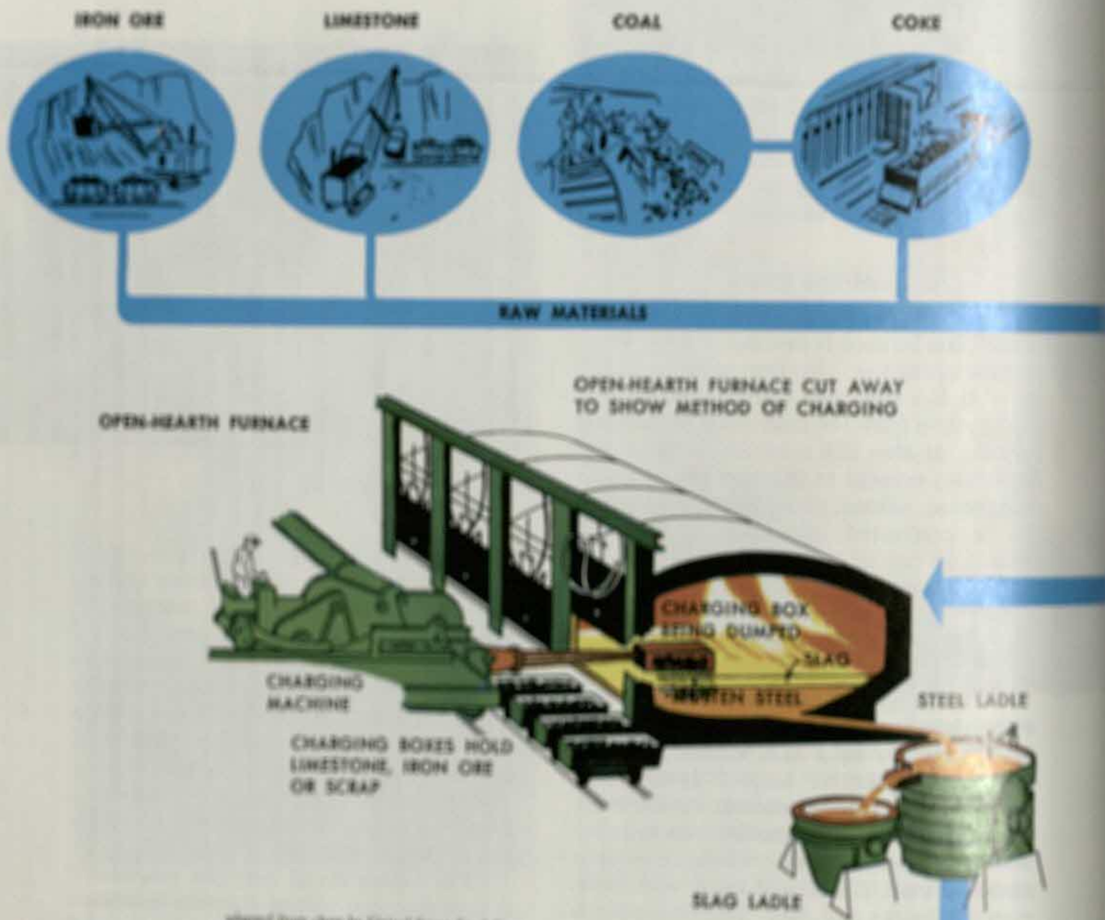
J. Cure

Microscopic section of steel.

The blown metal contains practically no manganese or silicon and very little carbon, but it has the original phosphorus and sulfur of pig iron. It also contains about 0.1 per cent of oxygen, dissolved in it because of the air blast. The oxygen must be removed before the steel is forged or rolled. This is done by adding an alloy of iron and manganese to the blown metal as it is emptied into the ladle. The manganese combines with the oxygen in the metal, forming a slag.

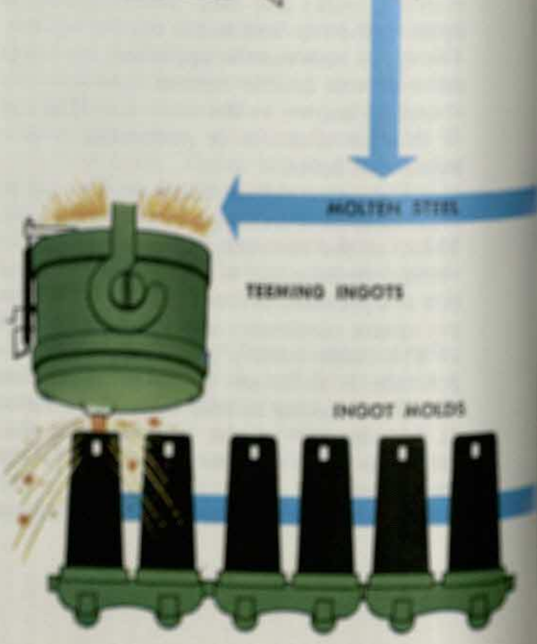
Since the invention of finer and higher-capacity processes for making steel, Bessemer production has steadily fallen off. Only a fraction of the existing Bessemer converters in the United States are used in preparing the hot-metal charge for open-hearth furnaces, which we shall describe next.

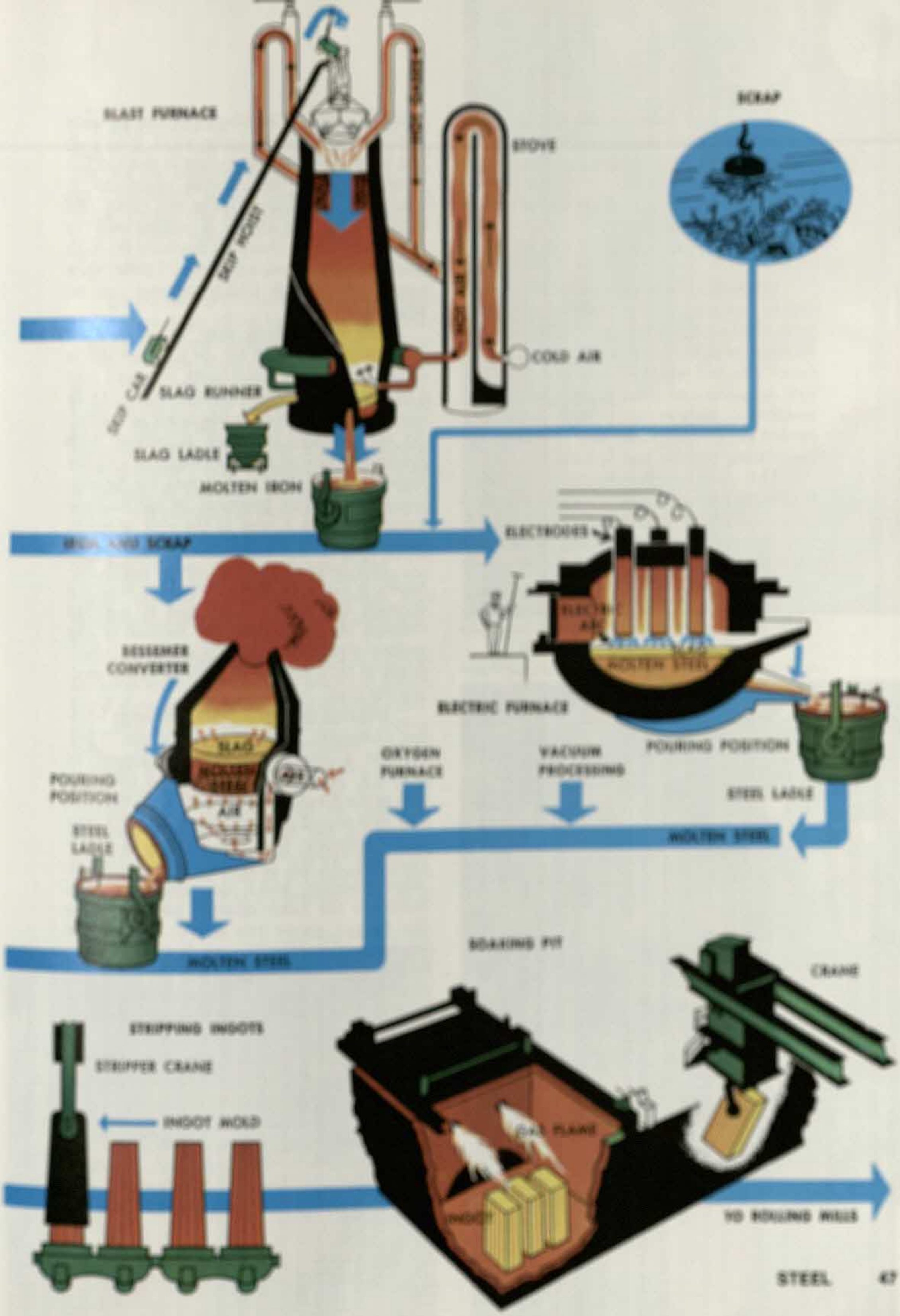
Bessemer steel, however, has certain


IRON ORE
LIMESTONE
COAL
COKE
RAW MATERIALS
OPEN-HEARTH FURNACE
OPEN-HEARTH FURNACE CUT AWAY TO SHOW METHOD OF CHARGING
CHARGING BOX BEING DUMPED
SLAG
MOLTEN STEEL
CHARGING MACHINE
CHARGING BOXES HOLD LIMESTONE, IRON ORE OR SCRAP
STEEL LADLE
SLAG LADLE

adapted from chart by United States Steel Corp.

The three principal materials for steelmaking are iron ore, limestone, and coal. In coke ovens, coal is made into coke for the blast furnace. Iron ore, coke, and limestone are charged into the blast furnace, which smelts the ore into molten pig iron. Pig iron and scrap steel are made into steel by one or the other of various processes. The molten steel that has been produced by one or the other of the processes, is poured into ingot molds. After the metal has cooled and solidified, the molds are removed from the ingots by a stripper—a pair of giant tongs, suspended from an overhead crane. The ingot is the first solid form of steel. Before being rolled, it is uniformly heated. To provide an even temperature from core to outer surface, the ingot is kept for hours in a soaking pit, a deep, covered furnace. It is then ready to be rolled. The first rolling converts the ingots into forms called blooms, slabs, and billets. In the finishing mills, the blooms, slabs, and billets are manufactured into steel products. Some of these are ready for use when they leave the finishing mills; in most cases, however, they are processed by various other industries into thousands of products.




BLAST FURNACE
SKIP HOIST
SKIP CAR
STOVE
HOT AIR
COLD AIR
SCRAP
SLAG RUNNER
SLAG LADLE
MOLTEN IRON
IRON AND SCRAP
ELECTRODES
ELECTRIC ARC
MOLTEN STEEL
ELECTRIC FURNACE
POURING POSITION
STEEL LADLE
BESSEMER CONVERTER
SLAG
MOLTEN STEEL
AIR
AIR
POURING POSITION
STEEL LADLE
OXYGEN FURNACE
VACUUM PROCESSING
MOLTEN STEEL
MOLTEN STEEL
SOAKING PIT
CRANE
STRIPPING INGOTS
STRIPPER CRANE
INGOT MOLD
GAS FLAME
INGOTS
TO ROLLING MILLS

advantages over other steels. It can be cut or machined into various shapes more conveniently than the ordinary steel processed by open-hearth furnaces. It can be welded and is consequently used for certain types of welded piping.

OPEN-HEARTH PROCESS

Much steel nowadays is made in *open-hearth furnaces*. In the United States, this method of steelmaking once accounted for 90 per cent of the total production. The furnaces process not only pig iron but also vast quantities of steel scrap—junked automobiles, railway cars, and other discarded steel objects and also the waste accumulating in mills and factories.

The open-hearth furnace is so called because its hearth, or floor, is exposed to the sweep of the flames that melt the metal. The furnace is a rectangular, completely enclosed brick structure, built to operate at 1,600° Celsius. The charge of the furnace consists of pig iron, scrap steel, iron ore, and limestone. The limestone is used in the same way as in the smelting operation. It combines with impurities in the metal and forms a slag. The charge is carried into the open hearth by a charging machine through mechanically operated doors. These have peepholes through which melting can be observed.

The fuel, which may be natural or coke-oven gas, oil or tar, or a combination of two or more of these fuels, is blown into a burner above each end of the hearth. Only one of these burners is operated at a time. At the burner, the fuel is mixed with previously heated air and is ignited. As the flame sweeps down and across the hearth, smoke and other products of combustion escape through a port at the end opposite the burner.

In a large number of open-hearth furnaces, a *lance* (a sort of pipe) is inserted through the roof and oxygen is injected through the lance onto the surface of the molten steel. This operation serves effectively to burn out the impurities in the molten pig iron.

Beneath the furnace are two large heating chambers, called *regenerators*. They contain a checkerboard arrangement of firebrick. As the hot products of combustion in the furnace pass out through the port and into one of the chambers on their way to the chimney, they heat the bricks of the chamber. At the same time air enters the other chamber, which has been previously heated in the same manner, on its way to the burner above the hearth. When the bricks in this chamber no longer give up enough heat, the operation is reversed. Fuel and air are now directed to the other burner. The chamber that has been heating the incoming air now becomes heated by the products of combustion. This change takes place every ten to fifteen minutes.

Generally, about twelve hours are required to produce a *heat*, or batch, of open-hearth steel. When a heat has been completed, the furnace is tapped. A plug in the back wall is blasted or knocked out, and the molten steel flows into a great ladle set

Steel sheet, one of the end products of steel making, comes off "cold-rollers" in a finishing mill. Steel sheet is used in automobile bodies and oil drums.

U.S. Steel

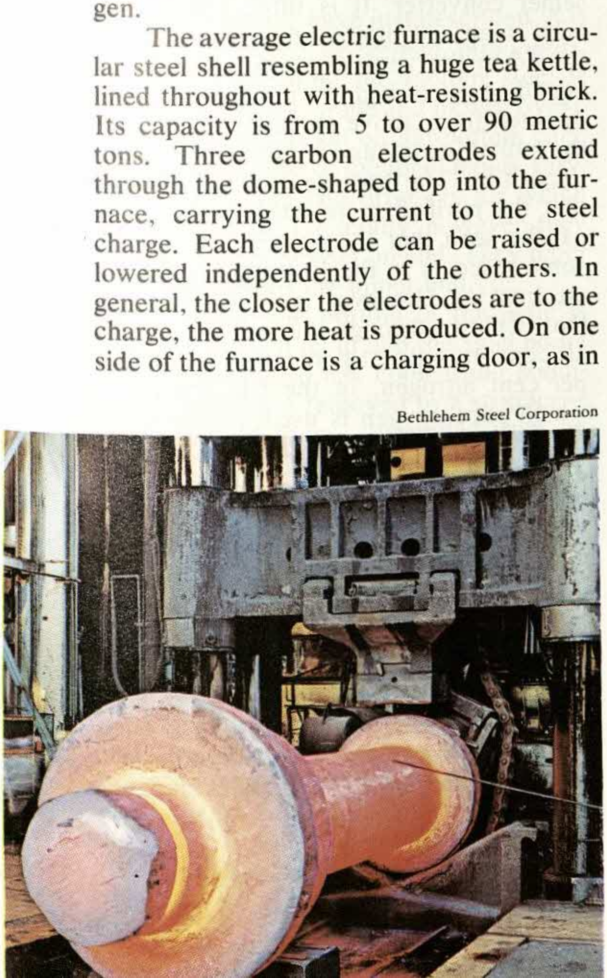
in a pit in back of the furnace. The liquid slag floats on top and overflows into a slag pot. As the molten steel fills the ladle, the final additions of alloying substances are made, giving the steel the exact composition carefully specified by the customer.

ELECTRIC FURNACE

Steels that are to contain a particularly high percentage of various alloying metals are made almost exclusively in the *electric furnace*. Some plain carbon steels and low alloy steels are also produced by this process. In the electric furnace, steel is melted by the heat of an electric arc (really a continuous spark), which provides a temperature of about 1,800° Celsius. No fuel or air is needed in the electric furnace and, as a result, it is possible to control the amount of oxygen entering the furnace. Thus the oxygen content of the steel can be kept to the minimum. Besides, expensive alloying elements can be added without much loss through oxidation, or combining with oxygen.

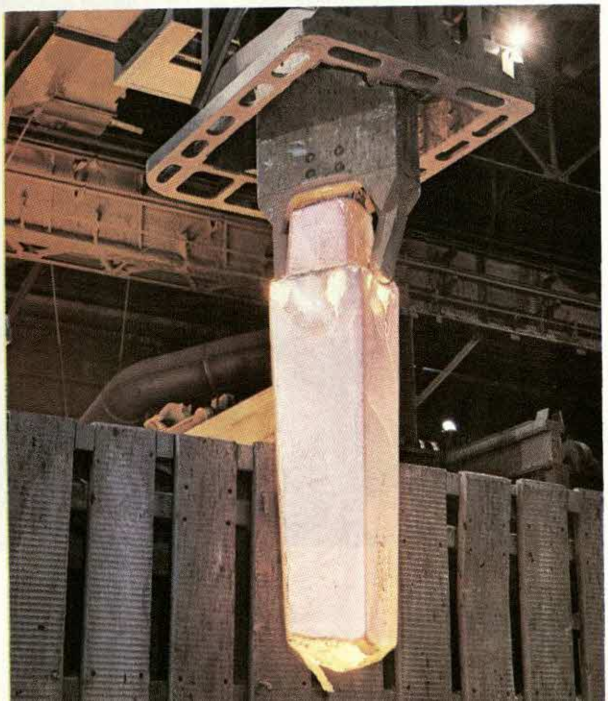
The average electric furnace is a circular steel shell resembling a huge tea kettle, lined throughout with heat-resisting brick. Its capacity is from 5 to over 90 metric tons. Three carbon electrodes extend through the dome-shaped top into the furnace, carrying the current to the steel charge. Each electrode can be raised or lowered independently of the others. In general, the closer the electrodes are to the charge, the more heat is produced. On one side of the furnace is a charging door, as in

Bethlehem Steel Corporation



top and bottom right photos, Republic Steel Corporation

Top: Steel blooms are manufactured in a blooming mill. A steel ingot, such as the one below, is passed back and forth several times until the desired shape is achieved. Bottom left: steel being forged for industrial use. Forging is used to make products such as train wheels, axles, and other simple, heavy objects. Workers turn the steel and hammer it until the right shape is formed.



the open-hearth furnace. On the other side is the tapping spout. The furnace can be tilted to pour off the molten steel and slag through this spout.

The method most frequently used in the operation of the electric furnace is the *cold-melt process,* so called because cold steel scrap makes up the charge. With the furnace charged, the current is turned on. As each electrode is lowered, electric current jumps the gap between the electrode and the scrap, thus forming an arc. A violent noise like crackling gunfire is heard within the furnace as the arcs leap and break. The intense heat they generate melts the charge until the entire mass is seething.

There are two chief stages in the cold-melt process. In the first, the scrap is completely melted. Iron ore is added to the molten metal in order to oxidize silicon, manganese, phosphorus, and carbon. A slag is formed. It floats on top of the molten steel and is skimmed off with wooden rakes. In the second stage, a new slag is formed by adding materials such as calcium oxide and ferrosilicon, an iron-silicon alloy. The calcium oxide acts to reduce sulfur and carbon. The ferrosilicon removes oxygen and helps remove sulfur.

In the second stage, carefully measured amounts of alloying metals are added and the temperature is adjusted so that reactions take place at the proper rate. After a total of four to twelve hours, according to the size of the furnace and the kind of steel that is being made, the heat is ready to be tapped. During the tapping, aluminum pellets may be thrown into the ladle to counteract oxidation by air.

Bethlehem Steel Corporation

Steel wire is manufactured by drawing steel through narrow holes, or dies. Exceedingly thin wire can be formed by passing the steel through successively smaller holes.

OXYGEN (LD) PROCESS

The *oxygen steelmaking process* has become increasingly important. It was developed in Austria by Linnz and Donnewitz, and is sometimes known as the *LD process,* from the first letters of their names. Introduced into the United States in 1954, it proved to be most effective. The LD process is now very important in the United States. It rivals, if not surpasses, the open-hearth method in volume of steel production.

In the LD process, the furnace is a lined vessel, shaped something like a Bessemer converter. It is tilted and charged with scrap and molten iron. Then it is returned to the vertical position and flux is added. A jet of high-purity oxygen is now directed from above through a lance onto the molten metal, and it serves to burn out impurities. The furnace is tilted again so that the purified metal may be tapped. It can be seen that the process is similar in some respects to the Bessemer method of steelmaking. However, in the latter, it is air that is blown through the molten iron, and air contains only 21 percent oxygen and 78 per cent nitrogen. In the LD process, in which pure oxygen is used, nitrogen does not enter the steel in significant amounts. This is most important, since nitrogen makes steel altogether too brittle for certain end purposes.

VACUUM PROCESSING

Vacuum processing causes steels to acquire improved mechanical and physical properties. In vacuum melting, the refining action takes place in a special vacuum melting chamber. The heat is furnished by electric means, such as induction and the electric arc. In vacuum degassing, molten steel is poured into a high-vacuum chamber in order to remove unwanted gases. The vacuum causes the stream of molten metal to separate into droplets. These are freed from the gases they contain by the time they reform again. The main purpose of vacuum processing—in both the melting and degassing operations—is to prevent unwanted contamination with gases during the charging, melting, and tapping operations. Vacuum-processed steel is used, among other things, for turbine shafts and high-stress ball and roller bearings. It serves also in parts for aircraft and space vehicles, where extreme and varying conditions are often encountered.

SHAPING STEEL

TEEMING

After steel has been processed by one of the methods we have just described, it is ready to be poured, or *teemed,* into *ingots.* The ladle containing the molten steel is lifted by an electric crane and moved over a row of ingot molds set on flat-bottom cars. The size and shape of the ingot molds vary, depending on the end products for which they will be used. Generally, however, they look like long boxes set on end. They taper somewhat toward the upper end.

A hole in the bottom of the ladle is opened over each mold and the steel pours in. After the metal has cooled and solidified, the molds are removed by a stripper—a pair of giant tongs, suspended from an overhead crane. The stripper catches hold of two lugs near the top of each mold and lifts, or strips, the mold from the ingot. The ingot is the first solid form of steel. Open hearth ingots for rolling may weigh 5 to 25 metric tons. Bessemer and electric furnace ingots usually weigh less.

ROLLING

The next step in the shaping of steel is *rolling,* or passing the steel between rolls. This process modifies the internal structure of the steel and also serves to form it into desired shapes. Before the metal can be rolled, the ingot must be uniformly heated. To provide a temperature of 1,200° Celsius from core to outer surface, the ingot is kept in a deep, covered furnace, known as a soaking pit, for a period of from one to eight hours. This process is called *soaking.*

The first rolling of steel converts ingots into forms called *blooms, billets,* and *slabs.* A bloom is generally square or rectangular in cross section. Its cross-sectional area is more than 230 square centimeters. Billets may also be either square or rectangular in cross section. Their cross section is smaller than that of blooms. In general, slabs are wider and flatter than billets.

The most generally used type of *blooming mill* has two smooth, cylindrical rolls, made of chilled cast iron or special alloy steel. These rolls, turning in opposite directions like a clothes wringer, grip the plastic, hot steel and pull it through, making it thinner and longer. By moving levers, the *roller*—the operator in charge of the rolling operation—can reverse the direction of the rolls and can pass the ingot back and forth. Each time the rolls are brought a little closer together, so that after each pass the ingot is flatter and longer. From time to time the ingot is turned over, so that the sides are also thoroughly worked. This type of blooming mill is called a *two-high*—that is, two-rolls-high—*reversing mill.* Blooms are also prepared in three-roll mills, called *three-high mills.*

After the ingot has become a bloom, it goes along a runway to a heavy blade, called a *shear,* which trims off its two ragged ends and cuts it into sections. The steel that is trimmed goes back to the furnace as scrap.

The process of rolling ingots into slabs is much the same as the bloom-preparing process, except that four-high reversing mills are used. In these, the ingot passes only between the two middle rolls, which are smaller than the other two. The heavier top and bottom rolls back up and strengthen the working rolls, producing a more even thickness in the wide slab. The *slabbing mill* also has vertical rolls to work on the sides of the slab. The slab is passed back and forth between the two sets of rolls until it has reached the desired dimensions.

Billets ordinarily are rolled from blooms. The *billet mill* is usually placed next to the blooming mill so that the ingot can be reduced to blooms, and then from blooms to billets, without reheating. Some billet mills are continuous: that is, they have a number of *stands*, or sets of rolls, placed next to one another. The steel is passed without stopping from one stand to the next. Each stand reduces the thickness a little more, running slightly faster to take up the increase in length of the steel.

STEEL PRODUCTS

Blooms, billets, and slabs are converted in *finishing mills* into products such as beams, plates, sheets, and bars. This is done chiefly by rolling. Other methods are also used to improve the quality of steel products and add to their usefulness.

Rails. Rails, among the most important of steel products, are rolled from white-hot blooms of open-hearth steel by a method much like that used in making billets. Grooved rolls squeeze the bloom, through a number of changes, into rail shape. After leaving the mill, the rails are cooled slowly to insure maximum strength and evenness. They are then straightened in a press, and bolt holes are drilled through them.

Structural steel. Structural steel is very important in all kinds of modern construction where steel frameworks provide needed strength. Hundreds of structural shapes are produced for varying needs. In cross section, they may resemble various capital letters: H, I, L, T, and Z. An important shape is the *channel,* with flat bottom and two short sides. Structural steel is hot-rolled from blooms, through specially grooved rolls, just as rails are.

Bars. Bars, which are prepared by hot-rolling, are among the most widely used products of the steel industry. More are used for making automobile parts than for any other purpose. There is hardly any industry, however, that does not use bars in some way or other. They are rolled from billets in widely varying shapes—square, round, half-round, oval, hexagonal, octagonal, and flat. A substantial tonnage is *cold-drawn*—that is, the hot-rolled bar is cooled and pulled through a hole in a hard steel die. The die reduces the thickness of the bar very slightly, bringing it to the exact size required. It also burnishes the surface of the bar.

Plate, sheet, and strip. A large part of the steel made in the furnaces of the United States is rolled into flat forms. Flat pieces of steel, ranging from 0.5 to 5 centimeters in thickness, are called *plates*. They may go into railway cars, hulls of ships, or the sections of bridges. Thinner pieces over 60 centimeters wide are called *sheets.* They serve for automobile bodies, metal cabinets, gasoline drums, and the like. Still thinner and narrower pieces, known as *strip,* are cut up and manufactured into thousands of products, including razor blades, toys, and license plates.

A great deal of thin steel is made into *tinplate*—steel coated with tin. Much of this coated steel is used for tin cans, which are from 98 to 99.5 per cent steel. The tin protects both the container and its contents from chemical attack. Tinplate is also used for radio parts, toys, kitchenware, bottle caps, buttons, and signs.

Most tin-plating is done by the *electrolytic method*. The steel strip moves through a solution of tin salt, while an electric current passes from a pure tin electrode into the solution and through the steel. The current causes tin to be deposited on both surfaces of the steel strip. The strip then goes to an oven that melts the layers of tin. This method results in a superthin and even coating.

Steel is sometimes coated with zinc—a process called *galvanizing*—as a protection against rust. Galvanized steel is used for pails, drums, refuse cans, and corrugated roofing and siding. Steel coated with terne, an alloy of lead, is used principally for automobile fuel tanks. It is also employed for paint cans and oilcans, roofing, and downspouts. Because of the presence of lead, terneplate is never used in the manufacture of food containers. The coating process is much like that used in galvanizing and hot-dip tin-plating.

Wire. Another widely used steel product is wire. It serves for springs of all kinds, musical strings, nails, screws, tacks, bolts, pins, needles, strainers, eggbeaters, corkscrews, clothes hangers, birdcages, and thousands of other useful objects. Ropes of twisted wire are used for suspension bridges and hoisting apparatus. Wire can be drawn into a variety of cross-sectional shapes—round, square, hexagonal, octagonal, oval, half-oval, and triangular. Diameters range from 0.0025 to a little less than 2 centimeters.

All steel wire is drawn from rods,

THE PRINCIPAL ALLOYING ELEMENTS USED WITH STEEL

ELEMENT AND SYMBOL	REASON FOR USE	TYPICAL APPLICATIONS
Aluminum (Al)	Remove gases and impurities.	Seldom more than a trace remains, except in nitrided steel.
Chromium (Cr)	Small amounts improve hardening qualities; more than 10 per cent prevents rust.	Tools; machinery parts; stainless and heat- and acid-resisting steels.
Cobalt (Co)	Holds cutting edge at high temperatures. Improves electrical qualities.	High-speed cutting tools; permanent magnet steel.
Copper (Cu)	Retards rust.	Roofing and siding sheets, plates.
Lead (Pb)	When mixed with tin, forms a rust-resisting coating for steel. Small amounts alloyed with steel improve machinability.	Sheet steel for roofing, automobile gasoline tanks, etc.; machinery parts.
Manganese (Mn)	Small amounts remove gases from steel; 1 to 2 per cent increases strength and toughness; 12 per cent imparts great toughness and resistance to abrasion.	Small amounts present in all steels; 1 to 2 per cent used in rails; 12 per cent or more for frogs and switches and dredgebucket teeth.
Molybdenum (Mo)	Increases strength, ductility, and resistance to shock.	Tools; machinery parts; tubing for airplane fuselages.
Nickel (Ni)	Increases toughness, stiffness, strength, and ductility. In large amounts resists heat and acids.	Tools; machinery parts; stainless steels; heat- and acid-resisting steels.
Silicon (Si)	Small amounts remove gases from steel, increase strength and resiliency; 4 per cent imparts high electrical efficiency.	Small amounts present in all steels; automobile and railway car springs (with manganese); 4 per cent for transformers, motors, generators.
Tin (Sn)	Forms corrosion-resisting coating on steel.	Sanitary cans; kitchenware.
Tungsten (W)	Retains hardness and toughness at high temperatures.	High-speed cutting tools; magnets.
Vanadium (V)	Increases strength, ductility, and resiliency.	Tools; springs; machinery parts.
Zinc (Zn)	Forms corrosion-resisting coating on steel.	Galvanized roofing and siding sheets; wire fences; pails; and so on.

which have been previously rolled from billets in a rod mill. After a rod has been cleaned of scale and given a lime coating, it is drawn through a die of some harder material. The die hole is tapered, from the diameter of the rod, at the entrance, to the smaller desired diameter of the wire, at the exit end of the die. The die must be very hard to withstand the wear and pull of the steel. Only chilled cast iron, a few alloy steels, tungsten carbide, and diamonds are hard enough to serve for the drawing operation. Wire is generally drawn through a number of dies, each with a smaller hole than the one before.

Pipes and tubing. There is no clearcut distinction between pipes and tubing. Generally the term pipes refers to tubes that conduct liquids or gases, while those which are used for structural and mechanical purposes or occur in very small sizes are called tubing. There are a number of exceptions, however.

Pipes and tubes fall into two classes—*welded* and *seamless*. Welded pipes have a seam along the entire length. To make certain kinds of welded pipe, a red-hot, flat strip of steel is pulled through a *welding bell*—a funnel-shaped die. The steel strip is curled into the form of a pipe. Its edges fuse together to form a seam. Pipe larger than 10 centimeters in diameter is made from plates. These are bent into pipe shape by a series of rolls. The edges are then electrically welded.

Other pipes and tubes, such as those which must carry fluids under pressure, are seamless. Some are prepared by the so-called *piercing process*—the oldest and the most widespread method. In this process a heated, round billet passes between two barrellike rolls that are arranged with their long axes at a slight angle to each other. As the revolving rolls grip the hot billet, they squeeze two sides of it, causing the other two sides to bulge out. Since the billet is rotated, each side is alternately squeezed and bulged out. This action causes a hole to be formed at the center of the billet, along its axis.

At the same time the steel is pushed against a bullet-shaped bar, which passes through the hole created by the squeezing-bulging action and makes the hole fairly uniform in diameter. In this way, a seamless tube is prepared.

In a process called *extrusion*, the billet is heated until it glows white, and then is forced through a die by a powerful press. So great are the heat and pressure required for this particular process that molten glass is commonly used as a lubricant.

Seamless tubing is further processed by cold-drawing in the case of certain products, such as hypodermic needles. These must have smaller diameters, thinner walls, and better surface finishes than are possible when hot-working methods are employed. In the cold-drawing process, a seamless tube, formed by piercing or extrusion, is cooled and is then pulled through a special kind of die. In this, a stationary bar, called a *mandrel*, is held inside the tube as it is being formed and supports its walls. Tubing processed in this way has the strength and smooth surface typical of cold-worked steel.

Forging and casting. A considerable amount of steel is shaped by *forging* and *casting*. Forging is employed principally to make railway-train wheels, axles, and other heavy shafting. In making wheels, a disk-shaped piece of steel cut from a round bloom is heated and placed in a forging press. The top and bottom of the press are dies shaped like the two sides of the wheel. When the press closes under a weight of 9,000 metric tons, the plastic, hot steel spreads into the hollow shape. In the forging of axles, a red-hot bloom, supported by a chain, is pounded into the shape of an axle by a forge hammer. Workers turn the steel forging around with tongs under the hammer blows, until the axle is fully shaped by the process.

Castings are generally products that are too large or complicated in shape to be forged or rolled. They include the frames of locomotives, the rudders and propellers of ships, and various parts of machines. In preparing castings, molten steel is poured into a mold of the desired shape. It solidifies in this mold. The plant in which castings are prepared is called a *foundry*.

U.S. Steel

Hot steel, reduced in thickness, comes out of finishing stands of a hot strip mill at a rate of more than 700 meters a minute.

MODIFYING STEEL STRUCTURE

Steel seems to be smooth and even to the unaided eye. Examination under the microscope, however, reveals its structure as a mass of tiny grains, tightly packed and forming a definite pattern. Further analysis with the use of X rays reveals that the grains, in turn, have a submicroscopic crystal structure. When steel is deformed by some physical stress, such as rolling, drawing, or forging, the grain structure and pattern may be altered, thus setting up internal strains. The steelmaker can relieve these strains by various types of heat treatment.

The treatment known as *normalizing* modifies the submicroscopic crystal structure and the size and shape of the grains. The steel is heated to a certain high temperature at which the crystal changes take place, and then is allowed to cool in still air.

Annealing is a heat treatment that relieves extreme internal strains and results in greater softness and ductility. It is used on finished products as well as on steel destined for further working. In annealing, the steel is moderately heated, held at the given temperature for a time, and then allowed to cool very slowly. The temperature is not so high that crystal transformations take place, but just great enough to make the steel very plastic and permit the internal strains to be reduced.

In hardening operations, steel is heated and then *quenched*, or cooled, very rapidly, by plunging it into a liquid or subjecting it to a blast of cold air. The more rapid the cooling, the harder the steel becomes.

Tempering (sometimes called *drawing*) is a form of heat treatment applied to hardened steel, particularly when the metal has been subjected to very rapid quenching. In tempering, the degree of hardness is effectively controlled by reheating the metal within a narrow range of temperatures.

In what is known as *case hardening*, the chemical composition of the surface of the steel is changed. A case, or hardened surface, is developed on the finished steel object, while the core remains flexible.

CLASSES AND USES OF STEEL

Steels are divided into several classes on the basis of their composition, physical properties, the manufacturing processes applied in making them, and the uses to which they are put.

Plain carbon steels. These steels contain carbon and also small quantities of other elements—mostly manganese, phosphorus, sulfur, and silicon. These steels are generally made by the Bessemer or open-hearth processes. Some are also made in the electric furnace. Plain carbon steels are used for structural framework, automobile bodies, railway-car bodies, rails, plows, hoes, rakes, tin cans, gas and electric ranges, tacks, hairpins, and thousands of other objects.

Alloy steels. When steel is treated with an alloying element or elements (in addition to those found in ordinary steel) so as to change to properties of the metal noticeably, the resulting product is called an alloy steel. The table on page 53 shows the chief alloying elements and their effect on steel.

Alloy steels can withstand unusually severe stresses, heat, and wear. They are often used for axles, crankshafts, connecting rods, propeller blades, pressure vessels, and machine tools of all sorts. High-quality alloy steels are made by the electric-furnace process. Considerable quantities of common alloy steels, used for various purposes, are produced in the open-hearth furnace.

Stainless steels. Stainless steels are high-grade alloys that provide particularly effective protection against corrosion and tarnishing. Some of these alloys resist heat very well at elevated temperatures. Like other high-quality steels, they are made in the electric furnace. They all contain chromium. Many of them are also alloyed with nickel. Some require molybdenum and other elements. Stainless steels are used, among other things, for cutlery, surgical instruments, decorative trim, and machine parts.

Maraging steels. A group of steels called maraging steels were developed to serve the needs of space vehicles and other advanced devices. A typical maraging steel contains 18 per cent nickel, 9 per cent cobalt, and 5 per cent molybdenum, with small amounts of titanium and aluminum. Maraging steels are exceedingly strong. Some of them can withstand pressures of up to 19,000 kilograms per square centimeter.

Gulf Oil

Ships, such as this large tanker, are just one of the many major users of structural steel, plate steel, and other types of pure and alloyed steels.

ENGINES

by Theodore D. Benjamin

Muscular strength alone would never suffice to accomplish all the tasks that the human brain suggests. To help perform these tasks, people have used a variety of power sources—heat, wind, water, electricity, and nuclear reactors—to perform work.

Heat is among the most useful of the sources of power. It drives most land vehicles, marine craft, and aircraft. It serves to generate electricity in many types of generators. It operates blowers, pumps, certain types of fans, and many other devices.

Heat power is put to use in an engine. In all heat engines, the chemical reaction that takes place when fuel is burned imparts a high degree of kinetic energy (energy of motion) to countless gas molecules. Generally these particles strike certain movable parts, such as pistons or turbine vanes, and these movable parts provide driving force.

EARLY STEAM ENGINES

The third century Greek mathematician and physicist Hero of Alexandria was probably the first to show that heat energy could be used to perform work. He invented a steam engine called the *aeolipile* (Fig. 1), which worked on much the same principle as a modern rotary lawn sprinkler.

The aeolipile consisted of a globe mounted between two tubes projecting upward from a steam boiler. The bent upper ends of the tubes passed through holes in the globe, which could rotate freely. Two bent nozzles were attached at opposite sides of the globe. The water in the boiler was heated.The steam passed from the boiler through the upright tubes into the globe and then out through the bent nozzles attached to the globe. The reactive force of the steam issuing from the nozzles caused the globe to spin rapidly. Hero never put his aeolipile, which was a form of *steam turbine*, to any practical use.

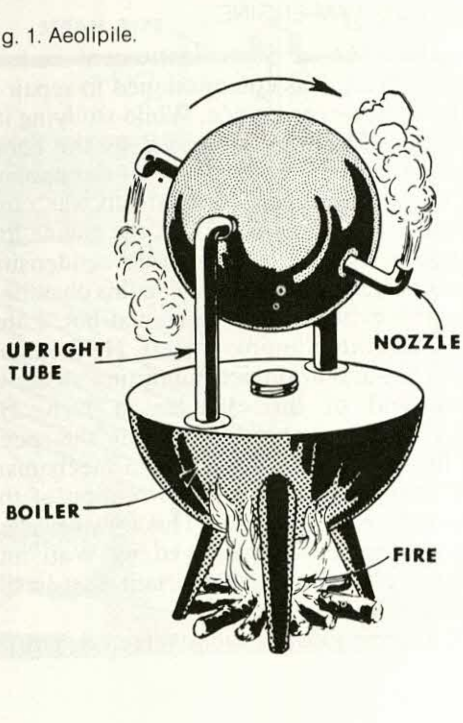
In 1629 an Italian engineer, Giovanni Branca, described another type of turbine —a device in which steam issuing from a boiler struck the vanes of a wheel and set it in motion.

Toward the end of the seventeenth century, the Frenchman Denis Papin published a description of a piston that was driven in a cylinder, open at the top, by the action of steam. Water was heated in the cylinder under the piston, and steam was generated. The power of the expanding steam pushed the piston upward. The source of heat was then removed from under the cylinder and the steam was allowed to condense. As a partial vacuum developed under the piston, atmospheric pressure pushed it down. This was one of the earliest versions of the *reciprocating engine*—one in which a piston moves to and fro in a cylinder.

THOMAS NEWCOMEN'S ENGINE

The Englishman Thomas Newcomen improved upon Papin's engine in the early

Fig. 1. Aeolipile.



years of the eighteenth century. Newcomen's engine also had a single cylinder in which a piston moved up and down. (Fig. 2). But in this engine, as soon as the steam had driven the piston up the cylinder, cold water was sprayed into the area below the piston. The steam, cooled suddenly by the water, condensed rapidly, and the piston moved down. Steam was then admitted to the cylinder again. The piston was attached to one end of an overhead beam called a *rocker arm. A pump rod*, which worked a pump, was connected to the other end. The up-and-down motion of the piston produced an up-and-down motion in the pump rod.

Newcomen engines were used quite extensively in England and Scotland in the eighteenth century to pump water from mines and wells. At first the operator had to admit steam and cold water, in turn, into the cylinder by means of hand valves. A young operator, Humphrey Potter, devised an ingenious system of cords and catches, by means of which the overhead beam opened and closed the valves as it rocked. Thus the engine became self-acting. Later a rod suspended from the beam worked the valves by means of *tappets,* or levers.

WATT'S STEAM ENGINE

In 1764, a Scots instrument maker, James Watt, was commissioned to repair a Newcomen-type engine. While studying its operation, he was impressed by the enormous waste of fuel because of the cooling of the cylinder each time steam was condensed in it. Watt improved the engine immensely by adding a separate condensing chamber. Steam condensed in this chamber, and the cylinder itself remained hot. Later he added other improvements. He invented a double-action device, admitting steam to each end of the cylinder in turn. He provided a governor to regulate the speed of the engine. He developed a mechanism for changing the to-and-fro motion of the piston to rotary motion. This *reciprocating steam engine*, as improved by Watt and others, played an all-important part in the Industrial Revolution.

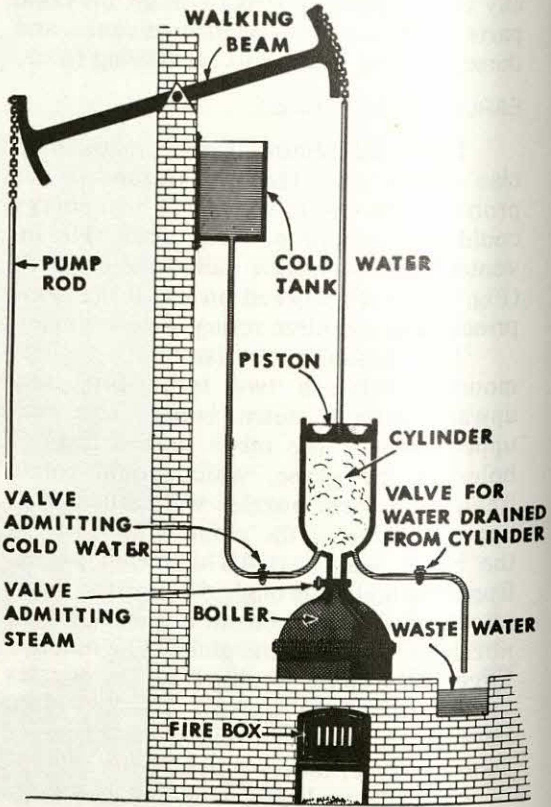
During most of the nineteenth century the reciprocating engine was the only practical type of steam engine. Then, during the 1880s, the first successful turbines were built by Sir Charles A. Parsons in England and Carl G.P. de Laval in Sweden. In the years that followed the steam turbine was greatly improved. It competed with the reciprocating steam engine and even replaced it for certain purposes.

BOILERS

In the modern steam engine the heat energy released by fuel is applied to water in a *boiler*. The steam that is generated serves to perform work. Almost any fuel that can release energy—coal, oil, wood, and several radioactive isotopes—can be used to heat water and thus to generate the steam that will run the engine.

The earliest boilers were simply airtight metal containers. A fire was built under them and the water contained was

Fig. 2. Newcomen engine.



turned into steam. These early boilers were very unsatisfactory. They were quite likely to explode when pressure was increased beyond a certain point. Even if they withstood the powerful pressure of steam, they were most inefficient. Much of the heat that was produced escaped to the outer air and comparatively little was used to heat water.

Boilers have been vastly improved. Our knowledge of riveting and welding and our understanding of the properties of various metals permit us to build boilers that can withstand high pressures. We have also succeeded in bringing the heat and the water into closer contact, thus providing greater economy and effectiveness of operation.

There are two chief kinds of boilers—the water-tube and fire-tube types.

The *water-tube boiler* is used to run stationary engines in factories or power plants. Figure 3 shows its construction. Much of the water is in the tubing below the reservoir drum. Flames and heated air from the firebox play around the *water tubes* and against the bottom of the drum. By exposing such a large area to the action of the flames, heat absorption is greatly increased. Note the *steam dome* in the diagram. Steam issues from the boiler through a pipe whose open end is set in the dome. This arrangement prevents liquid water from being drawn through the pipe. The pipe is looped back over the firebox, as shown in the diagram, in order to increase the heat of the steam as it leaves the boiler. Such extremely hot steam is called *superheated steam.*

The *firetube boiler* is found in steam locomotives. From the firebox, flames are drawn through long horizontal tubes that extend from one end of the boiler to the other. This serves to bring the heat into intimate contact with the water in the boiler. Figure 4 shows the arrangement in a typical locomotive. Flames and heated air are drawn from the firebox through the tubes and up the smokestack. Exhaust steam from the cylinders is also sent up the smokestack. This produces a powerful draft that sucks the flames into the fire tubes. It also gives rise to the characteristic chugging sound of a locomotive.

EXTERNAL COMBUSTION ENGINES

In external combustion engines, the fuel that is used is burned outside of the

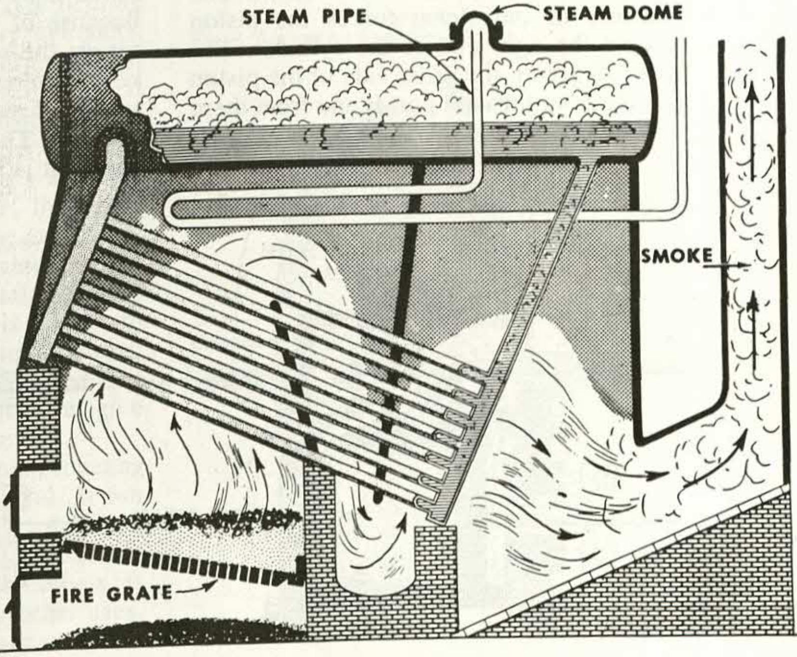


Fig. 3. A familiar type of water-tube boiler.

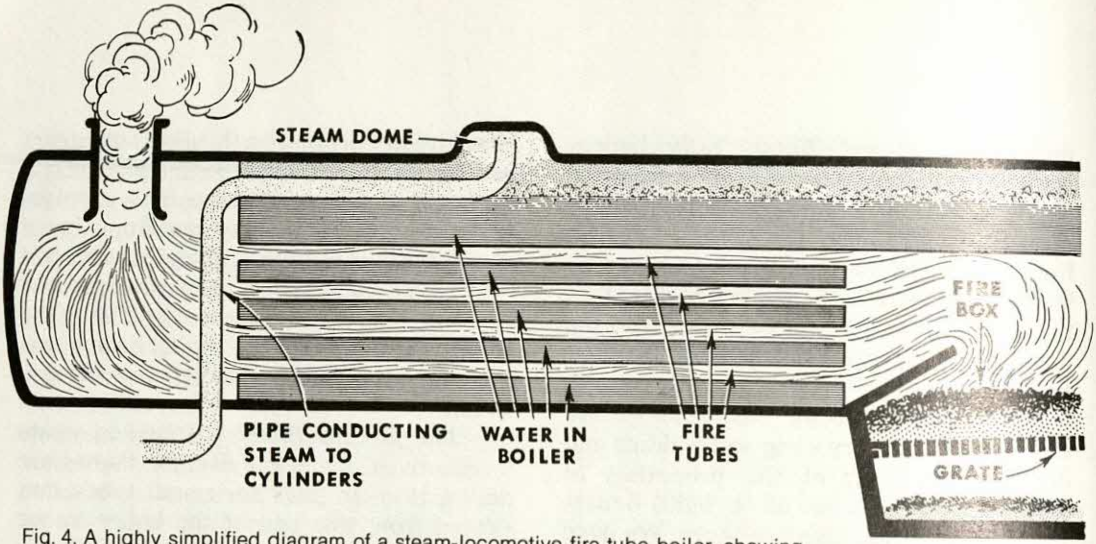


Fig. 4. A highly simplified diagram of a steam-locomotive fire-tube boiler, showing the basic principle involved.

engine. The reciprocating steam engine and the steam turbine are external combustion engines.

RECIPROCATING STEAM ENGINE

Figures 5 and 6 show the working parts of a simple reciprocating engine. From the boiler the steam is led through the *steam line* into the *steam chest*, which is simply a reservoir for holding the steam until it is admitted to the cylinder. From the steam chest the steam passes through port A and into the cylinder (see Fig. 5). The pressure of the steam forces the piston toward the right end of the cylinder. The spent steam on the other side of the piston is forced out through port B and from there into the *exhaust pipe*. When the piston is pushed to the end of its stroke, the *slide valve* moves to the left so that the steam now enters port B (Fig. 6). The piston is now pushed to the other end of the cylinder. The spent steam is pushed out through port A and from there to the exhaust pipe. Thus the piston moves back and forth in the cylinder as long as steam is admitted to the steam chest.

By means of a *crankshaft* the piston and its connecting rod turn a heavy wheel, called a *flywheel,* as shown in Figure 7. Because of its great inertia, the flywheel causes the engine to run smoothly and to keep running while the slide valve is changing the direction of the steam flow in the cylinder. The slide valve is operated by a *cam* that is mounted on the crankshaft, as

Fig. 5. Reciprocating engine. Steam enters through *A*. Spent steam passes through *B*.

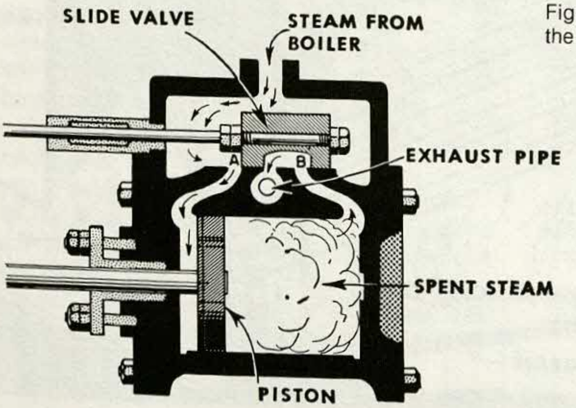
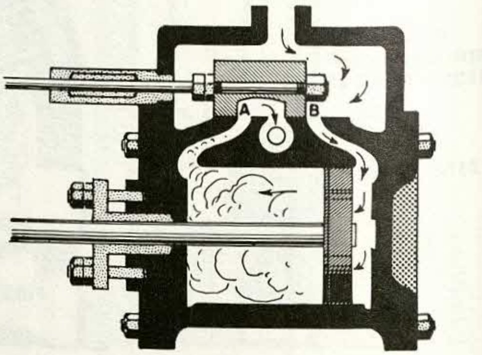


Fig. 6. In this case, steam is admitted through *B*, and the spent steam passes through *A*.



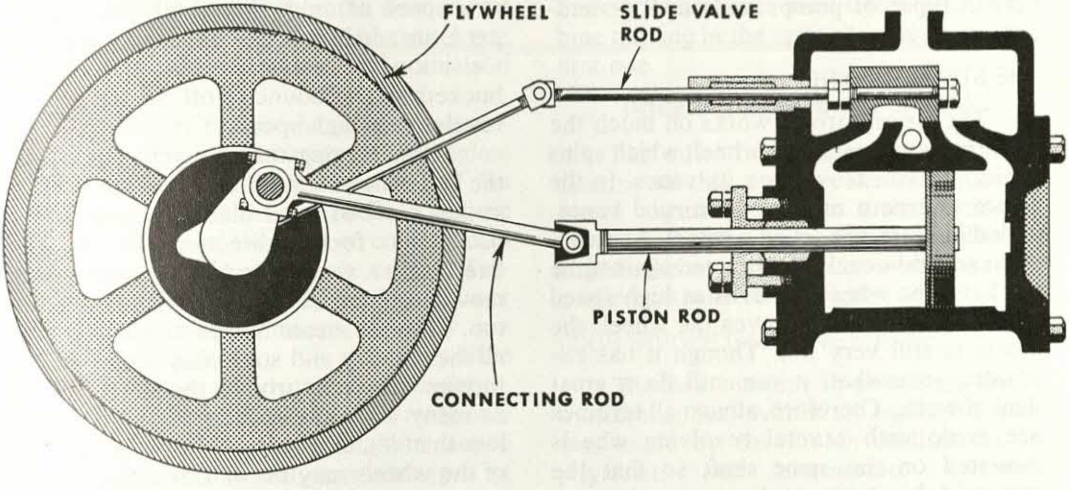


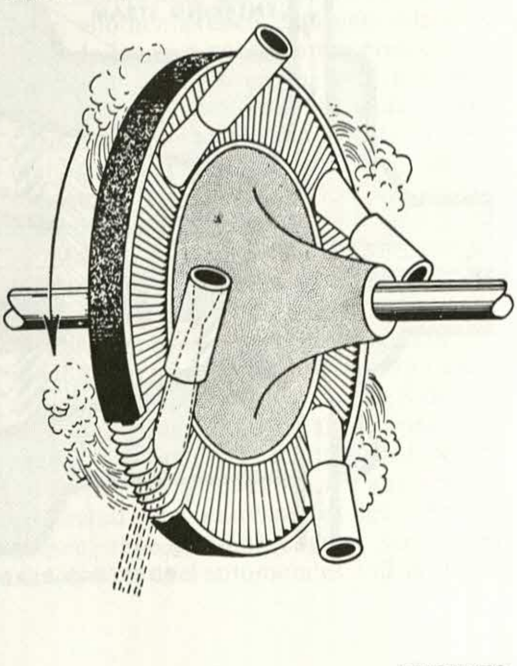
Fig. 7. A reciprocating steam engine with flywheel.

shown in Figure 7. As the crankshaft turns, the cam, which is connected to the slide-valve rod, moves the slide valve back and forth so that it closes ports A and B in turn at the propert time.

Types. There are many other types of reciprocating steam engines besides the one we have described here. Among the most important are the compound and uniflow engines. The *compound reciprocating steam engine* has two or more cylinders. Steam first enters a high-pressure cylinder, where it expands and performs work. It then enters two or more larger low-pressure cylinders where it also performs work. In the *uniflow engine*, steam enters at either end of the cylinder and leaves through a ring of exhaust ports around the center. As a result, the cool exhaust steam does not rob valuable heat from the intake ends of the cylinder. The piston is used to compress steam as well as to supply thrust. The temperature of the steam is raised as it is compressed. Both of these features give this engine a high heat efficiency.

Uses. At one time the reciprocating steam engine had no serious rival. It ran machines in industrial plants. It generated electricity in central power stations. It propelled ocean liners and locomotives. It operated pumps and had many other uses. The electric motor has now generally replaced it in factories, and the steam turbine has come into use in electric-power generating plants where steam is the power source. The reciprocating steam engine is still employed, to a limited extent, to run small seacraft. It has been largely replaced by the steam turbine in larger craft. It also serves at the present time as a power plant for some railroad locomotives, and it drives

Fig. 8. A simple steam turbine.



certain types of pumps and small generators.

THE STEAM TURBINE

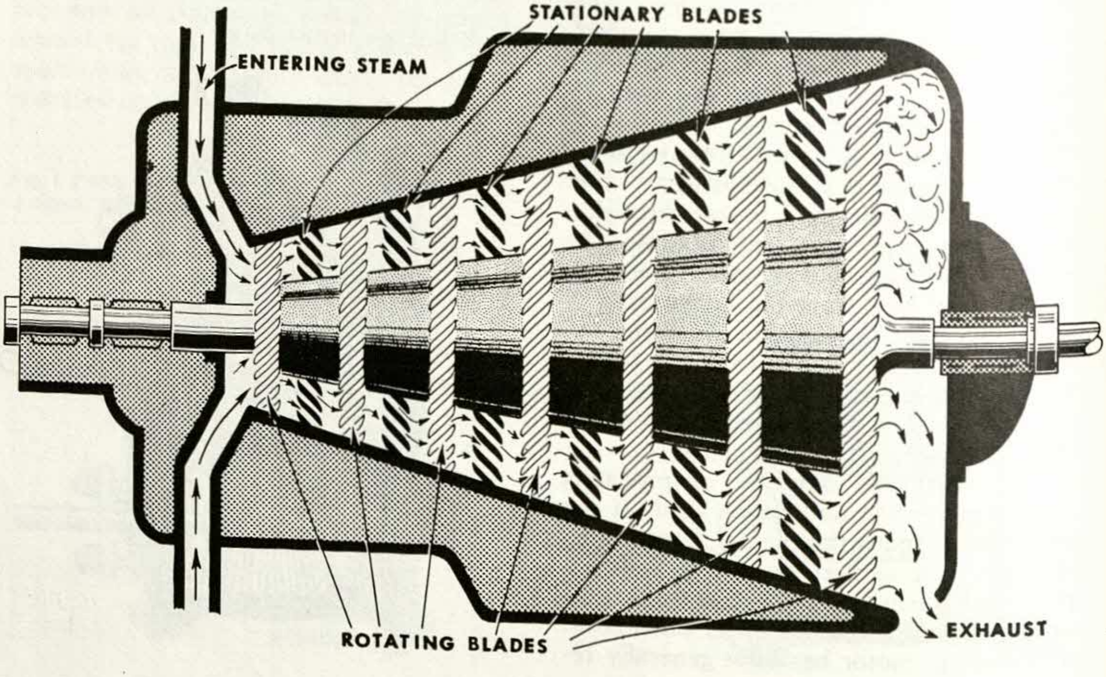
The steam turbine works on much the same principle as the pinwheel, which spins rapidly as you blow upon its vanes. In the steam turbine a number of curved vanes. called *buckets,* are set on a wheel. As steam from several nozzles is directed against the buckets, the wheel revolves at high speed (see Fig. 8). After it leaves the wheel, the steam is still very hot. Though it has expanded somewhat, it can still do a great deal of work. Therefore, almost all turbines are made with several revolving wheels mounted on the same shaft so that the power of the steam can be used more completely.

To make the steam strike each bucket at the proper angle and to extract as much energy from it as possible, the turbine is usually constructed as shown in Figure 9. Fixed blades are set between rotating wheels of blades, as shown. The steam enters through many nozzles and strikes the first set of rotating blades. It may enter at a speed of more than 1,600 kilometers per hour and at a temperature of over 500° Celsius. This steam strikes the curved buckets and, in bouncing off, sets the wheel revolving at high speed.

After leaving the first set of buckets, the steam has changed its direction. It now strikes a set of fixed blades, which turn it back to its former direction. Leaving the fixed blades, the steam hits the next set of movable blades and imparts a push to them too. Thus the steam makes its way through all the rotating and stationary blades of the turbine. In some turbines the steam strikes as many as 5,000 buckets in 24 wheels in less than $^{1}/_{30}$ of a second. The rim velocity of the wheels may be well over 1,600 kilometers per hour.

The force of the steam is so great as it leaves the nozzles and strikes the buckets of the first wheel that it can perform work by exerting great pressure on a very small surface. That is why the first wheels and their vanes are made comparatively small. As the steam strikes the buckets of one wheel after another, its force becomes somewhat spent. To utilize its remaining

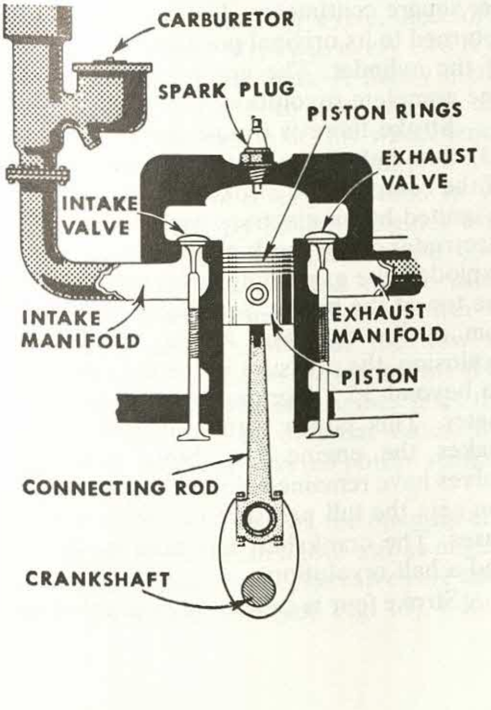
Fig. 9. Steam turbine, showing stationary and rotating blades.



energy as fully as possible, the diameter of the wheels and the size of their vanes are increased as they approach the outlet end of the turbine.

The steam turbine has certain advantages over the reciprocating steam engine. First, and perhaps most important, if the turbine is operated at high speeds, it is more efficient. More of the energy contained in the steam is used to drive the engine. Turbines occupy less space per horsepower than reciprocating engines. If they are properly aligned, they run with very little vibration. There are certain disadvantages, however. For one thing, the rotational speed of the turbine is so great that it can be directly coupled to only certain types of mechanisms, such as electrical generators in central power plants, centrifugal blowers, centrifugal pumps, and fans. When used as the power plant of a ship, a steam turbine must be fitted with intricate and massive reduction gears in order to provide the slower speeds at which propellers operate most efficiently. Another disadvantage of the turbine is that it cannot be reversed. To back water, a ship must use a second turbine moving in the opposite direction to the first one.

Fig. 10. Some of the important working parts of an automobile engine. A single cylinder is shown here in cross section.



INTERNAL COMBUSTION ENGINES

The other heat engines that we shall discuss in this article—the gasoline and diesel engines, the gas turbine, and so on—are known as *internal-combustion engines* because fuel is burned within the confining space of the engine itself.

FOUR-STROKE GASOLINE ENGINE

The first attempt to power an engine by burning fuel within an engine cylinder was made by the Dutch mathematician, physicist, and astronomer Christian Huygens about 1680. Huygens observed that when gunpowder was exploded in the barrel of a cannon, it generated a great volume of gas. This propelled a cannon ball out of the barrel at great speed and sent it whizzing through space. Huygens tried to construct an engine that would operate by means of a series of such powder explosions, but he failed. He found, for one thing, that it was extremely difficult to control an engine of this type.

The first practical internal-combustion engine was built by a French engineer, Jean-Joseph-Étienne Lenoir, in 1860. It used illuminating gas as a fuel. Two years later, another French engineer, Alphonse Beau de Rochas, set forth the principles of the *four-stroke cycle engine,* which we shall describe later. In 1876, Nikolaus August Otto, a German technician, constructed the first successful engine operating on the four-stroke principle. Like Lenoir's engine, it used illuminating gas.

Later, inventors sought to develop a carburetor in which gasoline could be vaporized so that it could be substituted for illuminating gas as a fuel. Gottlieb Daimler in Germany and Fernand Forest in France achieved this goal in 1885. In the following year Karl Benz, a German engineer, obtained a patent on a self-propelled vehicle powered by a gasoline engine and thus inaugurated the automobile age. At the present time gasoline engines serve principally to propel automobiles and airplanes,

FOUR-STROKE-CYCLE GASOLINE ENGINE

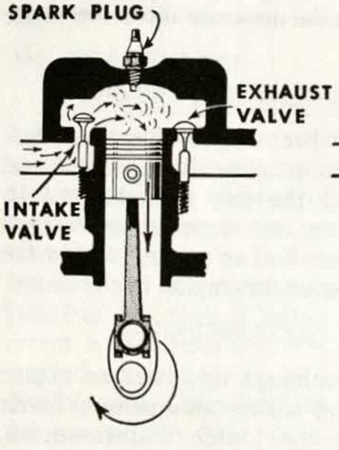


Fig. 11. Intake stroke.

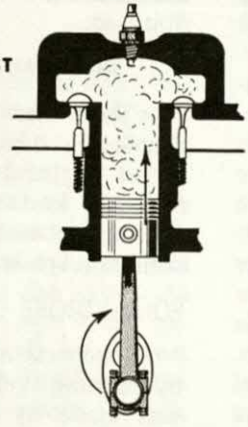


Fig. 12. Compression stroke.

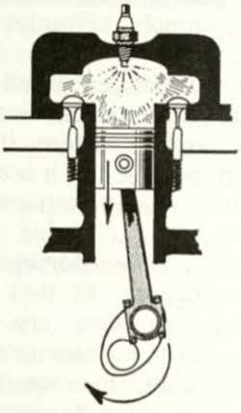


Fig. 13. Power stroke.

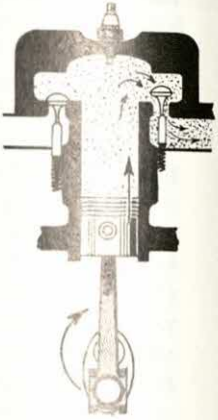


Fig. 14. Exhaust stroke.

though they are used for various other purposes.

How it works. Figure 10 shows a single cylinder of a typical U.S.-manufactured automobile engine, plus several other parts. The fuel that is burned in the cylinder is a mixture of gasoline vapor and air, prepared in the carburetor. This mixture is exploded by the heat of an electric spark between the electrodes of a spark plug. The explosion pushes the piston down in the cylinder. The connecting rod attached to the piston then turns a crankshaft. Flexible metal rings around the piston head are coated with lubricating oil. They fit so tightly against the walls of the cylinder that gases cannot make their way past the piston. The cylinder has two valves. One lets the fuel mixture in and the other lets the burned gases out.

Figures 11, 12, 13, and 14 show the operation of a single cylinder as it goes through the four steps or strokes of a four-stroke cycle. In the *intake stroke* (Fig. 11) the piston is pulled down from a position near the top of the cylinder. This is generally accomplished, when the engine is being started, by electrical energy from a battery operating an electric starter. As the piston moves down, the intake valve opens. The reduced air pressure within the cylinder allows the gasoline and air mixture from the carburetor to pass through the intake manifold and into the cylinder. During this stroke the exhaust valve is closed and the crankshaft makes one half of a revolution.

The second stroke is known as the *compression stroke* (Fig. 12). The starter continues to crank the engine. The intake valve closes and the piston moves upward. Since both valves are tightly closed during this stroke, the explosive mixture is compressed to form one sixth to one eighth of its original volume. The pressure within the cylinder may rise to about seven kilograms per square centimeter. The piston has now returned to its original position near the top of the cylinder. The crankshaft has made one complete revolution.

Stroke three is the *power stroke* (Fig. 13). Just before the piston reaches the top of the compression stroke, the fuel mixture is ignited by an electric spark between the electrodes of the spark plug. As the mixture explodes, the expanding gases push against the top of the piston, sending it to the bottom of the cylinder. At the moment of explosion, the pressure in the cylinder may go beyond 35 kilograms per square centimeter. This power stroke is really what makes the engine run. Note that both valves have remained closed so that the piston gets the full pressure of the expanding gases. The crankshaft has now made one and a half revolutions.

Stroke four is called the *exhaust stroke*

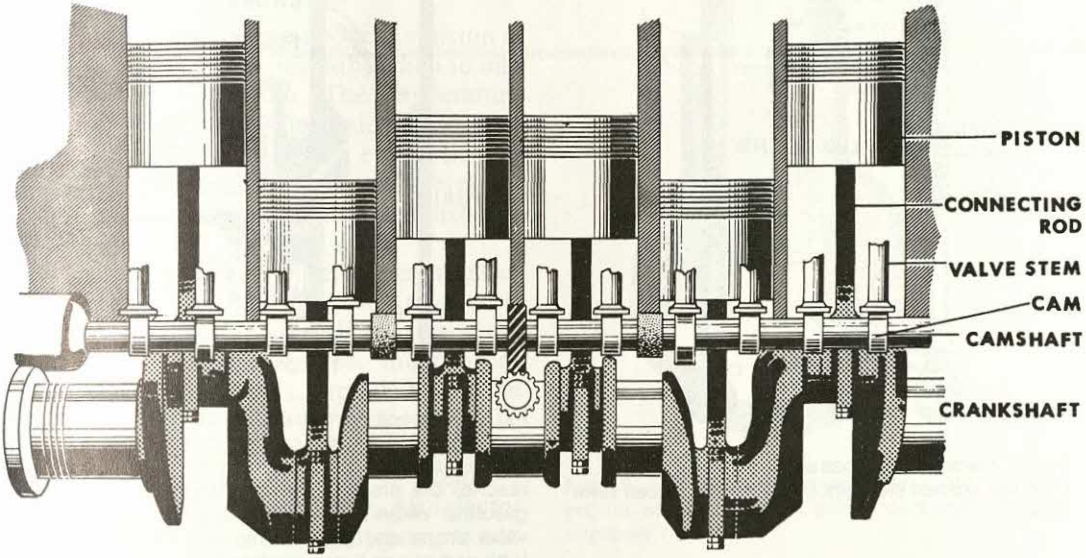


Fig. 15. Six-cylinder gasoline engine, showing the cylinders, camshaft, and crankshaft.

(Fig. 14). As the piston moves upward at the start of this stroke, the exhaust valve opens and the spent gases are pushed out through the exhaust manifold. At the end of the exhaust stroke, the cylinder is practically clear of the burned gases. The piston is once again in its top position and ready to start the intake stroke. By the end of the exhaust stroke, the crankshaft has made two revolutions. In every cycle, therefore, there is one power stroke to every two revolutions of the crankshaft. A heavy metal flywheel is attached to the end of the crankshaft. The inertia of this wheel tends to keep the engine running steadily.

A single-cylinder engine tends to vibrate excessively. By building engines with several cylinders and attaching the connecting rods of each piston to the same crankshaft, we can increase the power of the engine and smooth out the flow of power. Figure 15 shows the arrangement of cylinders in a six-cylinder engine. Since the cylinders are fired at different times, the crankshaft receives several power strokes at each revolution.

Timing. The timing of the opening and closing of the valves in a four-stroke engine is extremely important. The valves are controlled by a *camshaft* (see Fig. 15), a long straight shaft having projections called *cams*. There is one cam for each valve. The camshaft is rotated by being geared to the crankshaft. Since each valve must open only once for every two revolutions of the engine, the camshaft must be geared to turn at half the speed of the crankshaft. As the camshaft rotates, the *valve stem*, which rides on the cam, is pushed up when the high part of the cam reaches it. The valve opens into the cylinder against the pressure of a coiled spring. As the cam goes around, the spring closes the valve (Fig. 16). The cam, therefore, opens the valve and the spring closes it.

Several different systems are required to keep the engine running. The fuel system includes a *fuel pump*, which feeds the gasoline to the *carburetor*, and the carburetor, in which the gasoline and air are mixed in the proper proportion (see Fig. 17). In the ignition system the low voltage of a battery is increased by an induction coil, and the resulting high voltage is fed to the proper spark plug at the right time by a timing device called the *distributor*. In the cooling system water is pumped around the cylinders and air is blown over the radiator and engine to prevent overheating. The lubricating system feeds oil to the cylinder walls

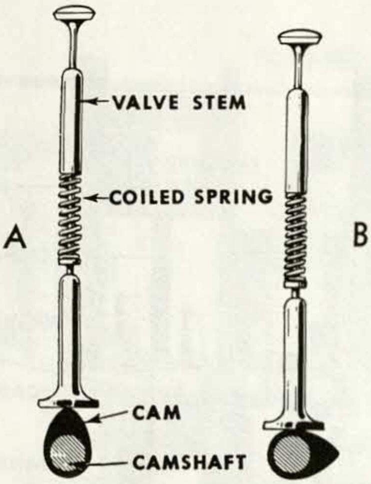


Fig. 16. Camshaft in cross section and valve stem. *A.* Cam has pushed stem up. *B.* Spring has forced stem down.

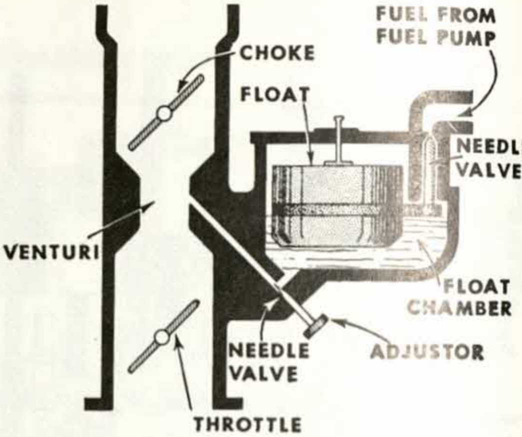


Fig. 17. How a carburetor works. Gasoline is fed to the float chamber by means of a fuel pump. A float pushes up a needle valve when the gasoline reaches the proper level, shutting off the flow of gasoline. When the gasoline level falls, the needle valve drops and gasoline enters. The carburetor tube narrows as it approaches the opening leading from the float chamber, forming the shape called a venturi. Gasoline is sprayed from the float chamber into this low-pressure region of the carburetor tube. The gasoline is mixed with air. The throttle controls the amount of the air-and-gasoline mixture admitted to the cylinders, and thus regulates the speed of the engine. The choke serves to control the proportion of air in the air-and-gasoline mixture fed to the cylinders. In a fuel-injection system, the carburetor is replaced by a pump, which in gasoline engines injects fuel into the intake manifold, and in diesel engines injects fuel directly into the cylinders.

and keeps the bearings from overheating because of friction.

TWO-STROKE GASOLINE ENGINE

Small engines such as outboard motors and model-airplane engines operate on a two-stroke cycle. An engine of this kind provides power once in each revolution. There is no complex valving system. The piston performs the work of valves by alternately covering and uncovering the intake and exhaust openings.

Figure 18 shows one type of two-stroke-cycle engine. As the piston rides up, it creates a partial vacuum in the crankcase. After the piston has moved up sufficiently, it uncovers the intake port. Air and gasoline vapor then fill the crankcase. In the meantime, the piston has compressed the mixture of air and gasoline that has accumulated above it. The mixture is ignited by a spark from the spark plug, and the piston is pushed downward. In its descent it closes the intake port. Then it uncovers the *exhaust port,* allowing the burned gases to escape, and the *bypass,* allowing a new charge of mixture to make its way to the area above the piston. With the compression of the new charge, another cycle begins.

The two-stroke-cycle engine receives power on each downstroke. The upper surface of the piston is shaped in such a way (see Fig. 18) that the incoming gases from the bypass are deflected to the top of the cylinder and do not mix with exhaust gas.

DIESEL ENGINES

When air is confined within a closed cylinder, its temperature rises as the pressure upon it increases. If the pressure is great enough, the air will become so hot that it will ignite a combustible mixture of gases. In 1892 Rudolf Diesel, a German engineer, conceived the idea of igniting the fuel in the cylinder of an internal-combustion engine by injecting it into highly compressed air. Five years later, he succeeded in building an engine—the diesel engine—based on this principle.

Imagine, if you will, a four-stroke-cycle engine in which, during the compres-

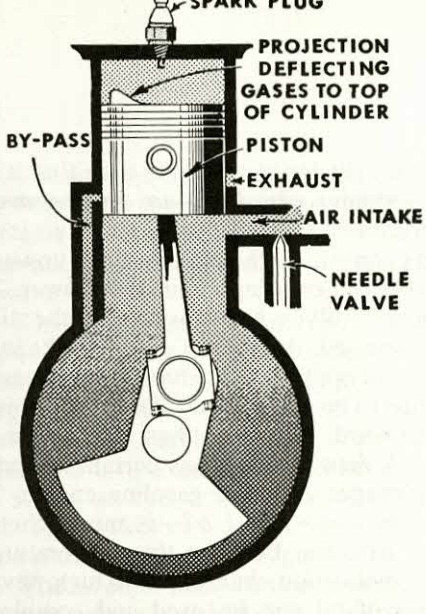


Fig. 18. Familiar type of two-stroke-cycle gasoline engine, which is used in small boats and in model airplanes.

sion stroke, the volume above the piston is reduced to one sixteenth rather than to one sixth of the maximum. The temperature resulting from the compression is so high that the fuel mixture ignites even when no spark is forthcoming. The diesel, therefore, can dispense with spark plugs and distributor.

The diesel engine differs from the gasoline engine in another important respect. If we compress the fuel-and-air mixture in the cylinder of a diesel engine, the mixture might preignite—that is, explode before the piston is ready to travel downward. To prevent this from taking place, the engine compresses air alone and not an explosive mixture of liquid fuel and air. An injector sprays the fuel into the highly compressed air only when the piston is ready for the downward stroke.

A four-stroke cycle of a diesel engine is shown in Figures 19, 20, 21, and 22. The four strokes of this cycle are (1) intake, (2) compression, (3) injection-power, and (4) exhaust. On the intake stroke, the piston moves downward and draws in air (Fig. 19). The intake valve then closes, and as the piston moves upward, the air is compressed (Fig. 20) into such a small space that its temperature rises to over 540° Celsius. At the proper moment the fuel is squirted into the cylinder by the injector and burns instantly (Fig. 21). The pressure in the cylinder rises greatly (it may reach more than 1,000 kilograms per square centimeter), and the piston is forced downward. As the piston rises upward again, the exhaust valve opens and the burned gases are pushed out (Fig. 22). This completes the cycle.

The fuel-injection system of the diesel engine is just about as complicated as the ignition system of the gasoline engine. The diesel's cylinder walls have to be thicker and heavier than those of the gasoline engine in order to withstand the higher pressures.

In the two-stroke-cycle diesel engine, diagramed in Figure 23, there are only a compression stroke and a power stroke. The engine fires once for every revolution of the crankshaft. As the piston nears the bottom of the cylinder, it uncovers openings through which compressed air, provided by a small *blower,* is introduced. Compressed air forces exhaust gases out through the open exhaust valves at the top

FOUR-STROKE-CYCLE DIESEL ENGINE

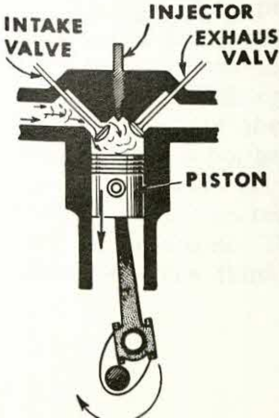


Fig. 19. Intake stroke.

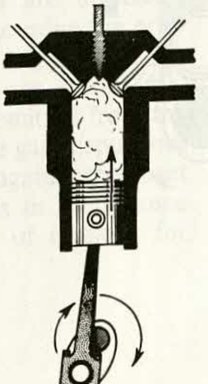


Fig. 20. Compression stroke.

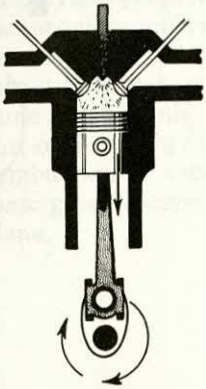


Fig. 21. Injection-power stroke.

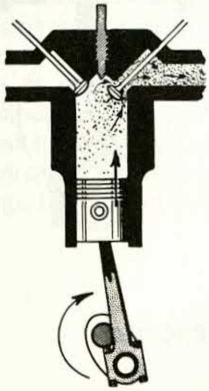


Fig. 22. Exhaust stroke.

of the cylinder at the same time that it fills the cylinder with fresh air. In one stroke, therefore, we have brought about air intake and exhaust. As the piston moves upward it covers the openings from the blower. The exhaust valves are closed and the air is compressed. At the top of the stroke injection and ignition of the fuel occur (diagram, right). The hot gases force the piston downward. The cycle then starts again.

A diesel engine has certain important advantages over the gasoline engine. The fuel it uses—*diesel oil*—is much cheaper than gasoline. Because the temperature in the combustion chamber is so high, several types of oil can be used and completely burned. If we used such fuels in a gasoline engine, they would not burn completely because of the lower temperature, and they would leave a deposit of carbon behind. Diesel engines are more efficient than gasoline engines, particularly at low speeds. On the other hand, the engines are comparatively heavy because of the thick cylinder walls needed to withstand the pressure due to the high compression. A diesel engine weighs considerably more per horse-power than a gasoline engine.

Diesel engines have been used in various types of surface ships and in submarines for many years. They are employed in great numbers to provide motive power for trains. The diesel-electric combination is particularly popular. In this, the powerful engines drive big electric generators. The electricity generated in this way not only provides abundant power for the electric motors that drive the locomotive but also furnishes light and heat. Locomotives of this type have replaced steam locomotives.

Diesel engines propel many automobiles, trucks, and passenger buses. They also serve the building industry. They operate power shovels and air compressors. The engines are employed on many farms to operate the electric generators that provide power, light, and heat. They drive tractors, and can pump water for various drainage and irrigation projects.

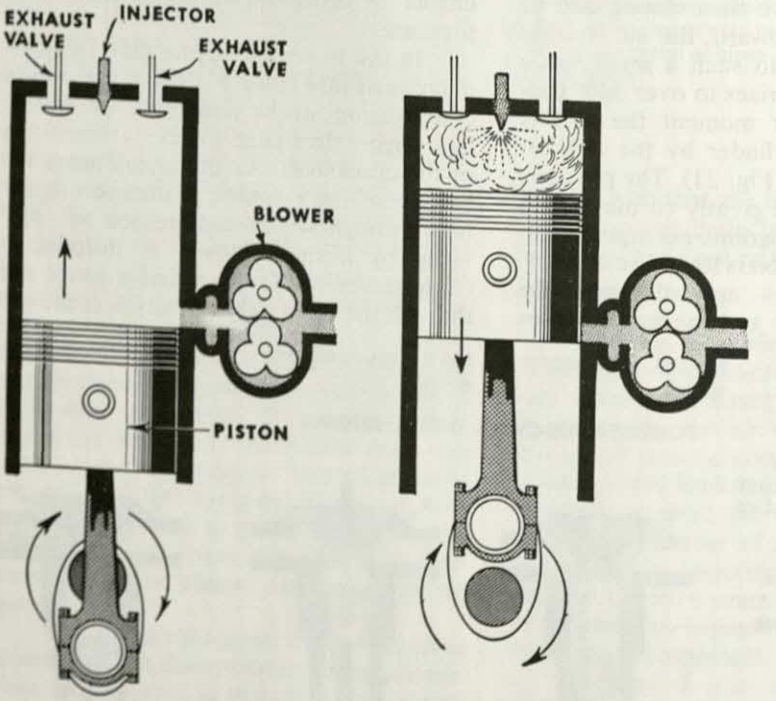


Fig. 23. The diagram at the far left shows the compression stroke of a two-stroke-cycle diesel engine. The power stroke is shown in the near-left diagram.

GAS TURBINE ENGINE

This type of internal-combustion engine, in which escaping gases operate a turbine, is known as a *gas turbine*. It shows great promise as a power plant not only for planes but also for locomotives, trucks, small ships, and dynamos. The gas turbine has few moving parts to get out of order. It is almost vibrationless in operation. It is very efficient. Many engineers believe that it will be one of the most important of our heat engines.

THE WANKEL ENGINE

The *Wankel,* or *rotary, engine,* is a gasoline-powered engine that uses spinning parts to produce the engine's driving force. The rotary parts do the job the pistons would in a conventional gasoline engine.

The rotary engine uses one or more triangular rotors that spin inside a housing. The inside of the housing constantly shifts and changes the dimensions of areas not occupied by the rotor. The three sides of the rotor form pockets with the inside surface of the rotor housing. These pockets get larger or smaller as the rotor slides and spins within the housing. The size changes within the chamber are the basis for the engines operation. An air-and-gasoline mixture is allowed to enter a large chamber and is then compressed as the chamber gets smaller. The compressed mixture is then ignited by a spark plug. The mixture explodes and sets the rotor spinning. The spinning rotor drives the shaft, and the process goes on.

OTHER ENGINES

In recent years, several new types of heat engines, based wholly or in part on the principle of jet propulsion, have been developed. These engines are discussed elsewhere. Let us briefly examine the principles on which the engines are based.

Jet-propelled aircraft are driven forward by jets of hot gases emitted from the rear of the engine. As these gases spurt out there is a vigorous recoil against the front part of the engine. This is in accordance with Newton's third law of motion: for every action there is an equal and opposite reaction. Since there is no thrust against the rear part of the plane, which is open to the outer air, the forward push drives the plane forward.

This jet thrust is found in the rocket engine. Fuel and oxygen (carried by the plane in the form of liquid oxygen or an oxygen compound) are ignited. The expanding gases resulting from combustion produce a thrust against the front part of the rocket as they stream out of the rear part. The rocket can operate in a vacuum since it carries its own oxygen.

The *turbojet* plane runs on a somewhat different principle. Air is drawn in from the atmosphere through intakes, situated in the nose or wings of the plane. The air is compressed, led into a combustion chamber, mixed with injected fuel and ignited. The gases of combustion that spurt toward the front of the plane meet the wall of incoming air from the compressor and are stopped. The gases that stream toward the rear spin a turbine wheel and are then expelled to the outer air. The reaction from the spurting gases provides thrust. The spinning turbine is connected to the main engine shaft. It drives the compressor, which is also mounted on this shaft.

The *ramjet* is a jet-propelled plane that has no compressor or turbine. Air is compressed by the so-called *ram effect* as it enters the engine from the intake at extremely high velocity. The compressed air then passes through the combustion chamber. Fuel is injected and the mixture of gases is ignited. The gases are then expelled from the rear of the plane, as in the turbojet.

In the plane known as the *turboprop,* the intake, compressor, combustion, and turbine units are like those of the turbojet. In the turboprop, however, it is the turbine that provides most of the driving power. As the turbine wheels spin on their shaft they turn a propeller, which is mounted on the same shaft. Only a comparatively small part of the energy released by the gases of combustion is used to provide thrust as these gases escape through the rear of the plane.

© Dick Durrance/Woodfin Camp & Assoc.

Robotic welders on an assembly line at a Chrysler plant in Michigan help to enhance productivity.

THE AUTOMOBILE

by Dennis Simanaitis

The automobile offers us personal mobility, a way to get from one place to another at our own time and pace. Its major impact on the way we live, work, and play has occurred in less than a century. What was once a curious contraption, used only by the eccentric, has evolved into the modern automobile.

With it, society has become more mobile. Travel that used to be arduous and dangerous is now routine. A home remote from a person's place of work and places of entertainment distant from either of these are taken for granted. However, this personal mobility has its disadvantages, too. Modern society is less tightly knit than before. The countryside is crisscrossed with roads and highways, often to the detriment of its natural beauty. City and suburban streets are clogged with rush-hour traffic. The automobile's petroleum fuel sources are limited, and political aspects complicate supply and demand. If uncontrolled, an auto's exhaust pollutants are harmful to the environment.

Nonetheless, modern society requires the personal mobility the auto provides. Engineering efforts are constantly improving the balance of advantages to disadvantages of the automobile. Such challenges are accelerating changes in the ways automobiles are designed, assembled, and used.

A DREAM OF PERSONAL MOBILITY

For centuries people dreamed of self-propelled vehicles that could travel on roads. Sails and windup springs were tried, but neither gave enough power or maneuverability. As early as 1665, a Jesuit priest stationed in China, Ferdinand Verbiest, built a working model of a steam-powered cart. But it was not until the 18th century that development of a practical steam engine made self-propelled vehicles a reality.

Nicolas-Joseph Cugnot, a French military engineer, is generally credited with building the first full-size self-propelled land vehicle, about 1770. This was a three-wheeled gun carriage powered by a steam engine driving the front wheel. Cugnot's carriage was almost unmaneuverable, and it overturned during testing, in what might be called the first auto accident. The carriage's large size and low power kept it from being practical.

STEAM CARRIAGES FOR THE ROAD

With improved steam engines came more successful self-propelled vehicles. By the 1830's, a number of steam carriages made regularly scheduled runs in and around the city of London, in competition with horse-drawn coaches. The coach companies protested the loss of business, and, at their instigation, the British Parliament passed the Road Locomotive Act in 1836. This law put a heavy tax on steam carriages and slowed their development in Great Britain for many years.

In the United States lack of highly developed road networks was the main problem. In many areas an agile horse was to remain the only practical means of personal transportation throughout the 1800's. Nevertheless, as railroads developed their own version of steam power, others applied it to road-going vehicles. In 1805, for example, American Oliver Evans displayed a steam-driven amphibious craft, a combination wagon and flatboat.

Although it had become an efficient power source by the middle of the 1800's, steam had limitations for road-going uses. A steam engine was, and remains to this day, a relatively heavy and bulky means of power generation. Yet many early autos relied on it, rather than trusting the less-developed internal-combustion engine.

A NEW COMPACT POWER SOURCE

The practical use of internal combustion is traceable to important developments made in the last half of the 1800's. In 1860 French inventor Étienne Lenoir built an internal-combustion engine that ran on illuminating gas. Two years later he mounted one of his engines on a carriage that had brief test runs around Paris.

Another Frenchman, Alphonse Beau de Rochas, worked out the theoretical details of a four-stroke internal-combustion engine, but it was left to a German inventor, Nikolaus H. Otto, to turn theory into practice. Otto's first successful four-cycle engine ran in 1876, and many stationary-power applications of this "otto-cycle" engine followed. First fueled on illuminating gas, the engines ran later on gasoline. Curiously enough, gasoline was considered an undesirable petroleum by-product at the time. Some plants producing valuable kerosene even piped the unwanted gasoline into nearby streams!

Two other Germans, Gottlieb Daimler and Karl Benz, independently designed engines of the otto-cycle type and installed them in horseless carriages, each around 1885. Both inventors offered their products for sale before 1890, and these commercial successes spurred interest in Europe and the United States.

By 1891, U.S. inventors Charles E. and J. Frank Duryea had built a gasoline-fueled buggy, generally considered to be the first of its type in this country. Before long many other Americans were entering this fledgling industry.

AN INDUSTRY GROWS

Auto production in the United States exceeded the rest of the world's by 1904. The country's broad industrial base, expanding economy, and relatively high standard of living made this possible. For a short period U.S. auto production was complicated by an 1895 patent issued to lawyer George B. Selden for an automobile powered by an internal-combustion engine. The Association of Licensed Automobile Manufacturers was formed to oversee the patent use, and many early U.S. automakers paid royalties. However, certain automakers, Henry Ford and Alexander Winton among them, refused to do so, and a lawsuit followed. The Selden patent was upheld initially, but in 1911 the court ruled that the independent manufacturers were not infringing the patent. The association

The 1908 Stanley Steamer could achieve speeds above 200 kilometers per hour.

© Henry Austin Clark, Jr.

was then disbanded, and automotive development in the U.S. surged ahead.

The earliest autos were essentially built one by one by skilled technicians. All their parts were handmade and each might have been slightly different from its counterpart. But before long the idea of standardized components, first used in firearms manufacture, was applied to the automobile. This introduction of interchangeable parts was very important. It meant that semiskilled laborers could replace the more highly paid technicians in auto assembly. This in turn paved the way for assembly-line mass production of autos that brought their cost within reach of average people.

Ransom E. Olds nurtured this concept in the production of his Oldsmobile car, and many others followed. The Society of Automotive Engineers, formed in 1905, provided automakers with a forum for such technical exchange. Today SAE remains at the forefront of automotive technology.

In 1914 Henry Ford astounded other automakers by paying his assembly-line workers $5 a day, more than twice the industry norm. Yet economies of mass production made Ford's Model T one of the least expensive cars available. The Model T was also one of the world's most popular and long-lived, with more than 15 million built between 1908 and 1927. The car was available in one color only—black—not because of any whim of Mr. Ford's, but rather for a sound technical reason: among the paints of the time, only black offered coverage and drying quick enough for Ford's assembly line.

The internal-combustion engine was not alone in powering early cars. Steam power persisted, along with electric power, well into the second decade of the century. The White and Stanley steamers, for example, were known for their power and performance; the Baker Electric, for its quietness and refinement. However, the bulkiness of steam power and the limited range of an electric car's batteries made them poor competitors with the quickly developing internal-combustion engine. Cadillac's introduction of electric self-starting in 1912 was only one innovation that made the gasoline-fueled engine more popular. By 1920, the internal-combustion engine reigned supreme.

50 YEARS OF STEADY EVOLUTION

The period 1910–1960 was one of steady evolution for the auto throughout the developed world. Many technical advances made it more reliable and increased its utility. Low-pressure balloon tires, for example, replaced the hard-riding, high-pressure variety in the 1920's. Four-wheel brakes appeared during the same period. Fully enclosed bodywork took the place of open tourers and made all-weather driving more practical. Safety glass lessened the hazards of accidents. Hydraulically actuated brakes introduced in the 1930's provided more reliable stopping power and independent front suspensions improved ride and comfort.

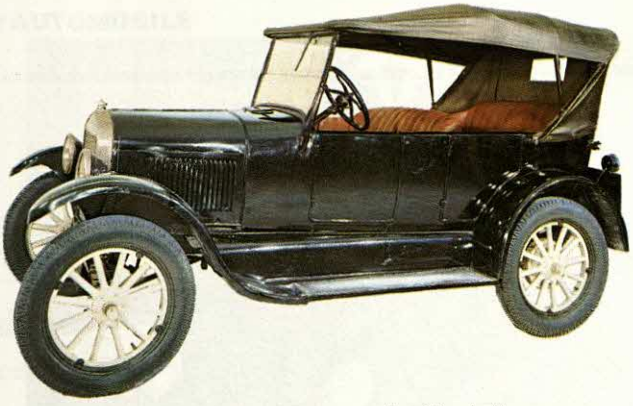
By the 1950's, comfort and convenience had become the main themes of auto design. Automatic transmissions, power-assisted steering and brakes, air conditioning, even electric window lifts were fitted. Cars became occasionally opulent expressions of their owners' personalities. During the same period small numbers of imported cars rekindled American interest in more basic automotive directions. Small, light, and fuel-efficient, these cars were a product of European developments, where traditionally higher fuel costs had fostered evolution of cars quite different from those in the United States.

DESIGN TRENDS

Three trends, involving the environment, fuel economy, and safety, have characterized more recent auto design. Indeed, the three are occasionally in direct conflict with each other, and this has provided new challenges for automotive engineering.

Studies of environmental pollution focused on the automobile during the 1960's. Auto exhaust contains a number of harmful chemicals: carbon monoxide, nitrogen oxides, and unburned hydrocarbons. In the presence of sunlight some of these recombine to form photochemical smog.

Beginning in the 1960's in California (where the problem was considered most serious), cars were fitted with various antipollution devices. Later the federal government's Clean Air Act of 1970 set a goal of diminishing auto pollution to one-tenth of its uncontrolled levels. Throughout the 1970's, increasingly stringent emission controls were incorporated into automotive designs. Unfortunately, many of these devices made engines less fuel efficient.



Bonnal-Renaulac/Yvon

A 1908 Model T Ford. Its success encouraged Ford to produce 15,000,000 more.

The need for fuel efficiency was emphasized in 1973–1974 and again in 1979, when manipulation of international petroleum supplies caused fuel shortages. The response of the U.S. government included formulating fuel-economy goals for auto manufacturers. Each automaker's total fleet was required to meet or better a specified miles-per-gallon figure for the given year. Combined with emission-control regulations, these requirements posed a crucial challenge to manufacturers selling their cars in the U.S. market. Also, the most fuel-efficient cars came from Europe and Japan, and automotive trade imbalances evolved into important economic issues around the world.

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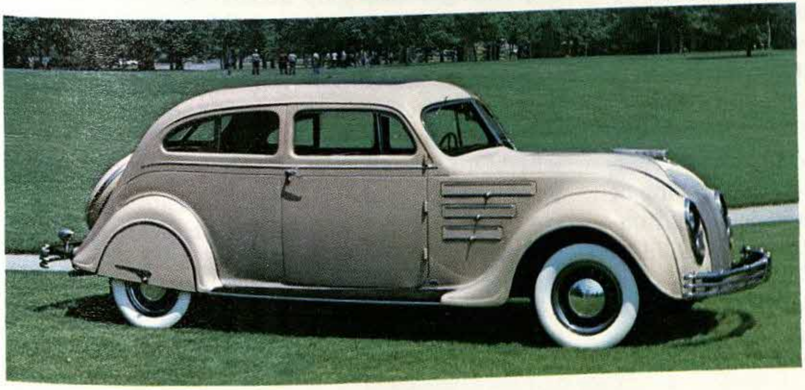


The 1934 Chrysler Airflow pioneered the use of streamlined design in automobiles.

Chet Bahn/Volkswagen Corp.

The VW Beetle played a major part in prompting the strong movement toward the purchase of foreign-made cars in the United States.

With the rise of consumer advocacy in the 1960's came serious questioning of the safety of autos in crashes. Federal regulations attempted to ensure crashworthiness of automobiles. Ironically, the initial attempts at making cars safer tended to make them heavier, too, in direct conflict with the goal of fuel efficiency.

Thus, the current period of auto design is full of challenges. At one time the automobile's chief attribute was that it ran at all. Today compatibility with its total environment is paramount.

THE MODERN AUTOMOBILE

Cars come in many sizes and styles. But any modern car is a complex assembly of the same basic subsystems. These are its engine, transmission and drivetrain, chassis, and bodywork.

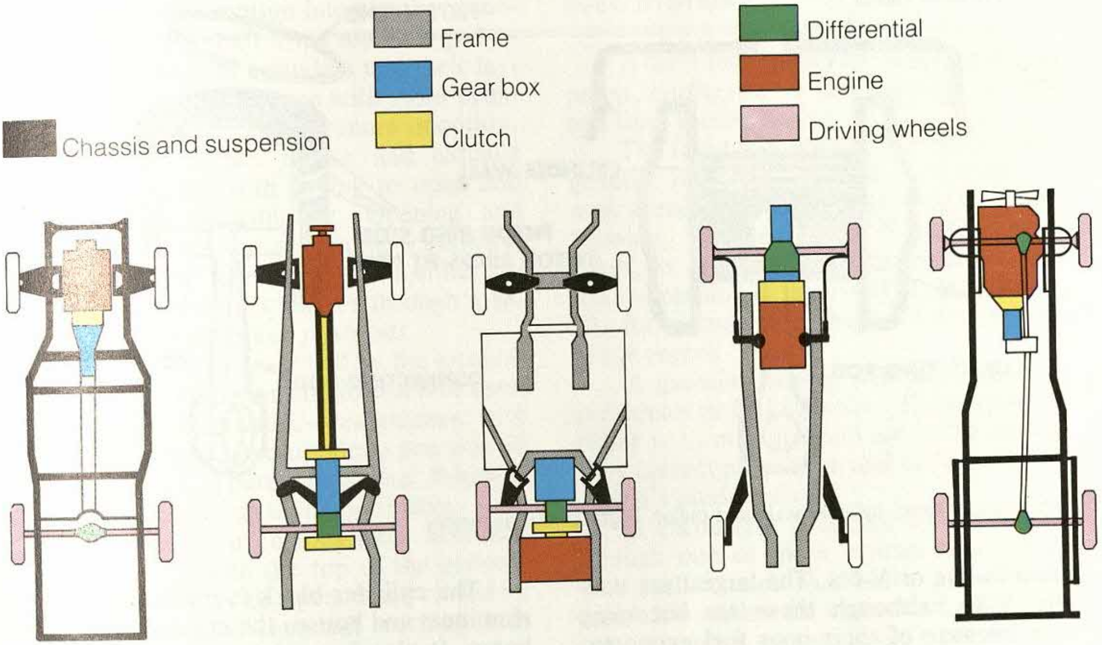
The engine converts chemical energy in its fuel into mechanical energy that propels the car. With the common internal-combustion engine, a controlled burning of fuel and air produces this mechanical energy in the form of a rotating shaft. The torque, or twisting force, of this shaft is transmitted to the car's driving wheels by the transmission and drivetrain. They also match the engine's rotating speed range to the desired range of car speed. Automobile engines produce useful power only in a limited range, roughly from 1,000 to 6,000 revolutions per minute (rpm). But, even at 80 kilometers per hour, a typical road wheel revolves at only 800 rpm, so reduction gearing is needed. The transmission, or gearbox, uses coupling devices and sets of gears to convert engine revolutions to a desired number of revolutions of the driving wheels. Transmissions may be manually shifted, leaving the choice of gear to the driver, or automatic, with shifting that responds to car speed and load.

The chassis, in its broadest sense, includes the structure supporting the car, together with its suspension, wheels and tires, brakes, and steering. A car's weight is transferred to the road through its suspension, wheels, and tires. The suspension has arms, springs, and dampers, or shock absorbers, that absorb road irregularities and counter side loads caused by cornering. Wheels are mounted with inflated tires, and a small area of the tires' tread surface is the car's only contact with the road. Brakes are used to slow or stop the car. A steering system changes the car's direction of travel by turning its front wheels.

The bodywork of most modern cars is actually part of the chassis, a unitary construction of welded steel. The bodywork encloses the car's mechanical components and its passenger compartment, and provides a place for luggage and storage. The passenger compartment contains controls and instrumentation for the car's operation. The total assembly plays an important role in passenger safety by absorbing energy in the event of an accident and protecting its properly restrained passengers.

Before describing each subsystem in more detail, we can note that there are several ways to arrange the engine and driving wheels of a car. The traditional approach has been to place the engine and transmission longitudinally at the front of the car with the rear wheels driven via a driveshaft connected to the rear-axle final drive unit. Many cars, especially larger ones, have this layout.

PARTS OF AN AUTOMOBILE



Other cars have their engines toward the rear, also driving the rear wheels. This can be done with either a mid engine or a fully rear one, the two distinguished by whether the engine is ahead of or behind the rear-wheel center line. The Volkswagen Beetle was a rear-engine car; the Fiat X1/9, a mid-engine car.

Another choice, increasingly popular in cars of all sizes, is a front engine driving the front wheels. This has good and bad points: it offers very efficient packaging of components, but it is complicated because the front wheels must both steer and propel the car. With front-wheel drive, the engine can be placed either longitudinally or transversely; the latter, an extremely compact layout is growing in favor. The Saab is a front-wheel-drive car with longitudinal engine. The Volkswagen Rabbit has a transverse engine driving its front wheels.

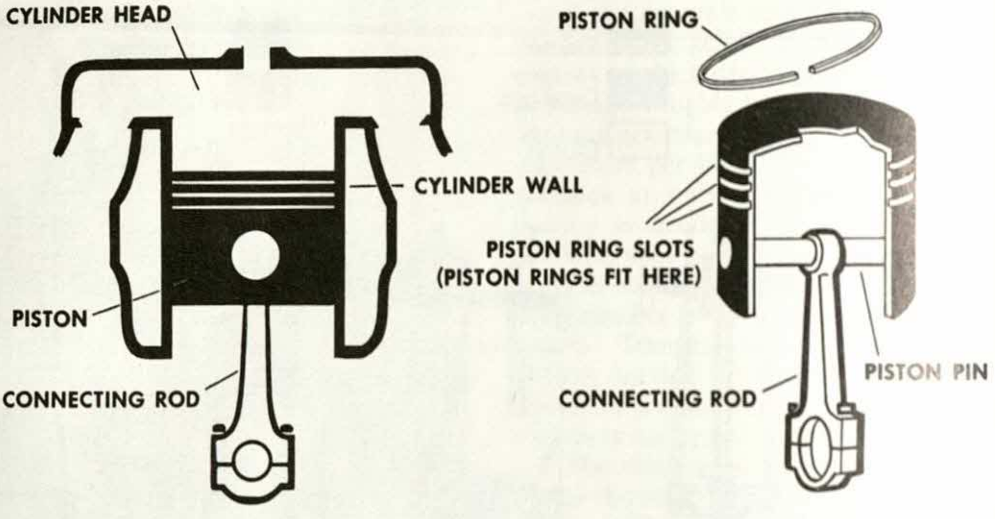
Each layout has advantages and disadvantages. It is likely, though, that front engine/front drive and traditional front engine/rear drive will continue to predominate. The first offers compactness; the second, relative ease of manufacturing and maintenance.

THE ENGINE

The article on Engines immediately preceding this one describes how a general internal-combustion engine operates. Here we focus on aspects that relate directly to the modern automobile.

An engine's size—its *displacement*—gives an idea of the power it produces. Displacement is measured by the total volume swept by the *pistons* as they travel up and down in the *cylinders*. The total volume may be given in cubic inches (sometimes abbreviated CID for cubic inch displacement), cubic centimeters (cc), or liters (one liter = 1,000 cc). A car's performance, however, depends on more than simply its displacement and power. Its weight is important, too. Cars with similar power and weight will have similar performance.

Modern automotive engines generally have four, six, or eight cylinders. These may be arranged in-line (in a row) or in a V. Each layout has advantages and disadvantages of manufacturing, balance, smoothness, and other factors. In general, small engines have four or fewer in-line cylinders. Those of medium displacement are



Left: cylinder head, cylinder wall, and piston. Right: piston assembly.

often in-line or V-6's. The largest are usually V-8's, although these are becoming rare because of their poor fuel economy. The important factors determining an engine's power and fuel economy are its displacement and mechanical details, not simply the number or arrangement of its cylinders.

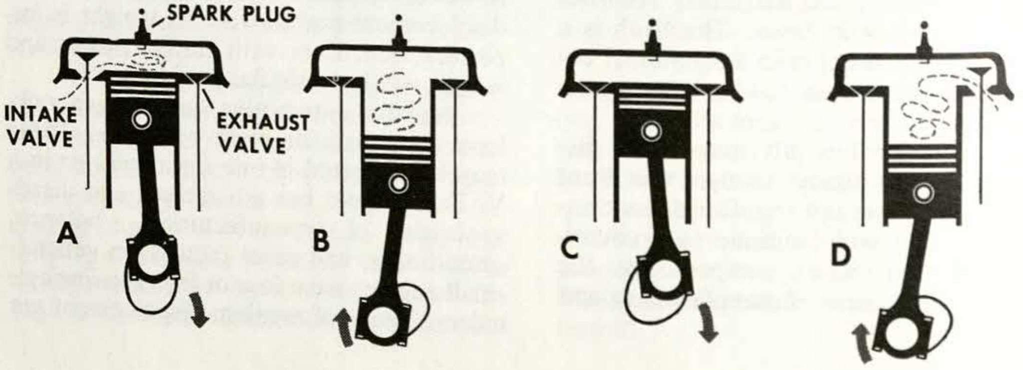
ENGINE SUBSYSTEMS

An engine has a *cylinder block, cylinder head, pistons* and *connecting rods, crankshaft,* and *valve mechanisms*. Other systems deliver its fuel, provide its electric supply, lubrication and cooling, and control its emissions.

The cylinder block is made of iron or aluminum and houses the engine's cylinder bores. It also has reinforced sections for *bearings* on which the crankshaft turns. A cylinder head on top of the block forms combustion chambers and has holes for the *intake* and *exhaust valves*. If the engine burns gasoline and thus needs a spark for ignition, the head also has threaded holes for the *spark plugs*. If a diesel, there are threaded holes for the diesel *fuel injectors* and for *glow plugs* used in start-up.

As each piston is driven downward by the expanding gases, power is transferred to an *arm* of the crankshaft by the piston's connecting rod. The crankshaft changes

Simplified diagram of a four-stroke automobile engine in operation. *A* represents the intake stroke; *B*, the compression stroke; *C*, the power stroke; and *D*, the exhaust stroke. Arrows indicate the direction in which the piston moves.



this straight-line motion into rotational motion. The crankshaft arms are arranged to suit the number of cylinders and their layout. In general, an engine with more cylinders will produce its power more smoothly.

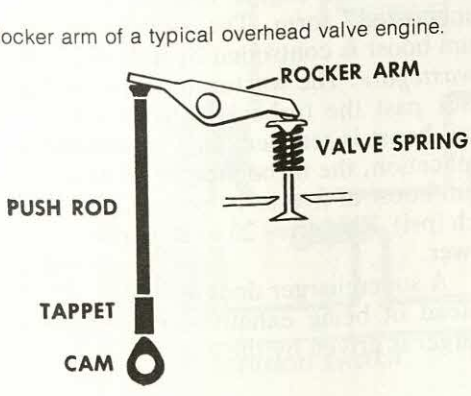
An engine has intake and exhaust valves, together with a way to open and close them mechanically. Opening and closing depends on a rotating *camshaft*, with eccentric lobes that push either directly on the *valve stems* or through a series of *rocker arms* and *pushrods*.

Valve gear is described by the location of valves and number and location of camshafts. Early cars had *L-head* engines, with valves arranged head-up along one side of the cylinders. There were also *T-heads*, with valves head-up along both sides.

Most modern engines have overhead valves angled with the top of the pistons. These valves may be opened and closed by a single overhead camshaft working both intake and exhaust valves. Another option is to have double overhead camshafts, with one for intake valves and the other for exhaust. Many older U.S. engines have overhead valves operated indirectly by pushrods and rocker arms, with a single camshaft in the cylinder block rather than on top of the cylinder head.

The choice of valve gear depends on many factors. Overhead valves give a good combustion chamber shape, and double overhead camshafts reduce the weight of valve gear. But these features are expensive and complicated in assembly. The single overhead camshaft is a good balance between these factors and efficiency of operation.

Rocker arm of a typical overhead valve engine.



FUEL SYSTEM

A car's fuel system has a *fuel tank*, *fuel pump*, *carburetor* or *fuel-injection system*, and lines linking these.

The fuel tank, holding from eight to 20 gallons, is usually located in a protected area ahead of the car's rear wheels. A safe location, required by U.S. safety standards, is important for keeping the fuel from exploding in the event of an accident. The fuel pump brings the fuel from the tank to the engine.

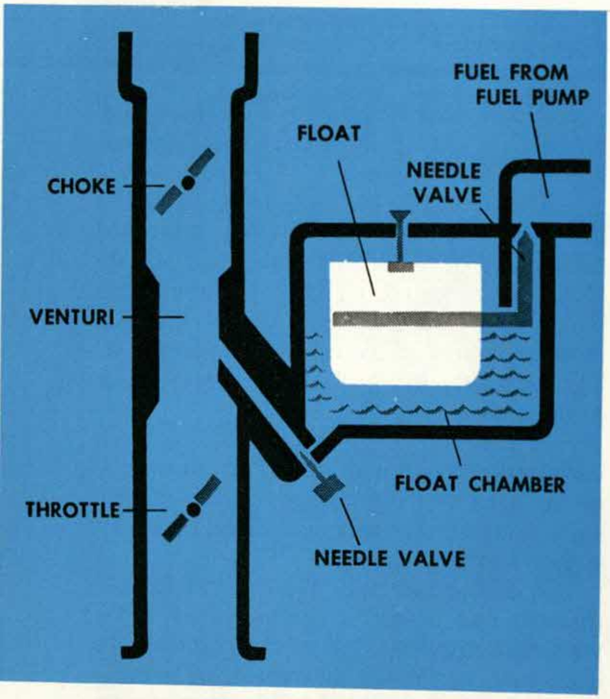
A gasoline engine will have either a carburetor or fuel injection. The purpose of either is to mix fuel and air in the chemically correct proportion and deliver it to the engine's intake valves.

A carburetor does this by passing air through one or more *venturi tubes* fitted with fuel nozzles. A *throttle plate* below each tube varies the amount of air admitted, depending on the driver's pressure on the *accelerator*. The varying air flow brings with it varying fuel flow in the correct proportion. Other carburetor devices allow for warm-up and emission control.

A fuel-injection system takes the place of a carburetor. It has a high-pressure pump and a metering and distribution system. In general, gasoline fuel injection gives better control of the fuel-air mixture from cylinder to cylinder. On the other hand, it is more expensive and more complicated than a carburetor.

With a diesel engine, fuel injection is the only way to get the fuel into the cylinders. A diesel operates by compression-ignition; that is, ignition takes place through the heat of compression alone with no electric spark needed. When a diesel's piston rises on its compression stroke, the air in the cylinder heats up and the injection system meters the right amount of fuel directly into the cylinder. This diesel fuel-air mixture burns more slowly than in gasoline combustion. This is one reason why diesel engines produce their power at lower speeds than a gasoline counterpart.

Also, a diesel engine operates without an air throttle. Roughly the same amount of air enters the engine at all times. The



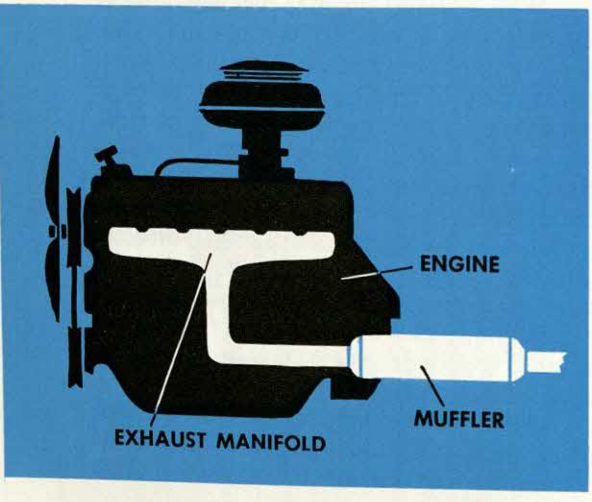
How the carburetor works. Gasoline is fed to the float chamber by means of the fuel pump. A float pushes up a needle valve when the gasoline reaches the proper level in the chamber, thus shutting off the flow of gasoline. When the gasoline level falls, the needle valve drops and gasoline enters the float chamber again. Air is pulled into the carburetor proper from above by the suction of the engine cylinders. The carburetor tube narrows as it approaches the opening leading from the float chamber; as a result it forms the shape known as a venturi. Gasoline is sprayed into the venturi from the float chamber and it is mixed with air. The throttle controls the amount of the air-and-gas mixture that is admitted to the cylinders, and it regulates the speed of the engine. The choke, which is near the other end of the carburetor, serves to control the proportion of air in the mixture.

amount of power produced depends on the amount of fuel injected. Since a diesel needs only a little fuel at light load, it gives very good fuel economy—20 to 30 percent better than its gasoline counterpart.

EXHAUST SYSTEM

A car's *exhaust system* connects the engine's exhaust to an *exhaust pipe, muffler,* and *tail pipe*. A muffler has a complicated collection of baffles and chambers. These take energy from the exhaust flow and reduce the noise of combustion. *Emission controls* are often part of the exhaust system.

Exhaust manifold and muffler.



TURBOCHARGING

Some engines, either gasoline or diesel, have *turbochargers,* devices that use exhaust heat to drive a small *turbine* and *compressor*. The turbocharger packs more air and fuel into the combustion chambers. Power output of an engine is increased with no change in its displacement. The turbocharger is designed to work at a higher engine speed and load, so under most driving conditions the engine runs in its normal "unboosted" form. The amount of maximum boost is controlled by a device called a *wastegate*. The wastegate routes exhaust gases past the turbocharger once the desired boost is reached. In a production-car application, the turbocharger gives a maximum boost of five to 10 pounds per square inch (psi). This gives 20 to 30 percent added power.

A supercharger does a similar job. But instead of being exhaust-driven, a supercharger is driven by the engine.

ELECTRICAL SYSTEM

A car's electrical system has a *storage battery* and *starter,* an *alternator,* an *ignition system* (if gasoline-fueled), a *lighting system,* and *accessories* such as instruments, radio, and heater-defroster fan.

Current from the battery causes the starter to turn. The starter is a powerful electric motor that operates the engine until it runs by itself. The battery stores the electric charge, and it is kept charged by the alternator, an alternating-current *generator* that is driven by the engine. Other devices automatically adjust the charging rate.

Diesel engines are usually equipped with glow plugs for heating their combustion chambers before starting. Once running, however, a diesel engine needs no further electrical means of maintaining combustion.

By contrast, a gasoline engine needs an ignition system to give a spark at each of its cylinders' spark plugs. The spark jumps a small *gap* in the spark plug and starts combustion just before the piston reaches the top of its compression stroke.

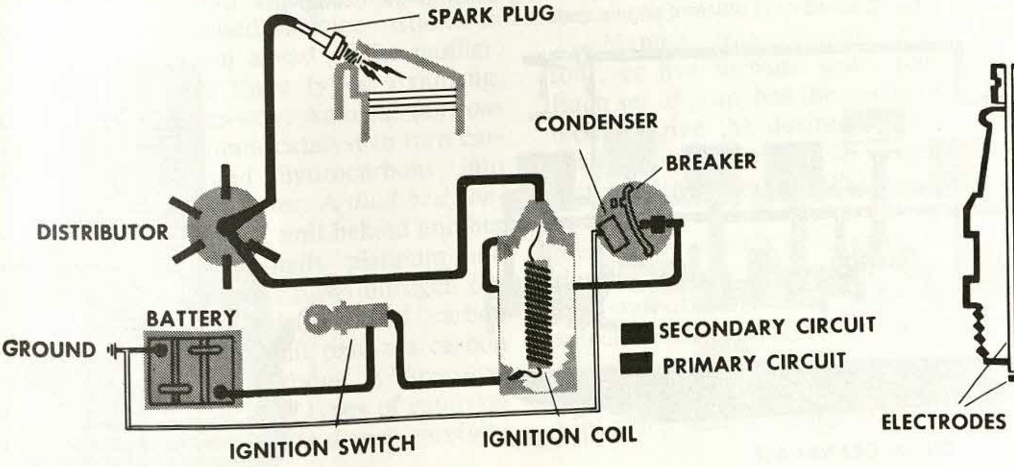
The spark plug's current comes from an electric *coil* sealed in a cylindrical case. The coil turns low-voltage current into the high-voltage current needed to jump the spark plug's gap. The high-voltage current is sent to the correct spark plug in the proper order by the *distributor,* a sort of rotary switch. The distributor also contains a device for setting the exact time of firing each spark plug. For many years this was a set of *breaker points* operated mechanically. More recently, electronic switching devices have replaced breaker points.

Also controlled is the *spark advance.* This is the needed lead time for the spark to start combustion under different engine speeds and loads. Previously done by vacuum and mechanical means, this has also been replaced by electronic control.

A car's lighting system is also electrically operated. Two or four *headlights* light the road ahead. These lights have *low beams* for ordinary driving and *high beams* to give added illumination. *Parking* and *side lights* aid nighttime visibility. Rear *brake lights* operate together with the driver's brake pedal. Directional *signal lights* at each corner of the car are used to signal a turn, and all four of these can blink to alert other vehicles to a hazard.

Headlights for U.S. cars are of the sealed-beam type. These have a tungsten filament, reflector, and lens sealed in a single molded unit. Those in Europe have the earlier bulb-type assembly, improved with introduction of halogen bulbs. A halogen bulb has its filament burning hotter and

The ignition system. An electric spark is needed to ignite the fuel and air mixture. The spark is supplied by the spark plug, shown at the right. At least 10,000 volts cross the spark gap on the plug.



brighter in a halogen gas, usually an iodide chemical. These bulbs are also more efficient electrically. For this reason U.S. headlight manufacturers have fitted halogen bulbs into the legally required sealed-beam headlights.

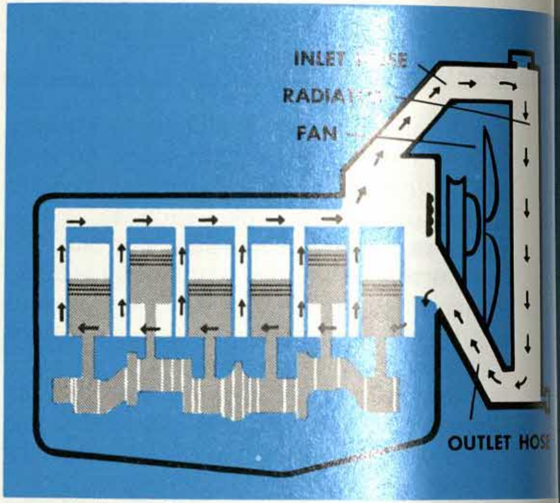
LUBRICATING SYSTEM

An engine's lubricating system has two jobs: it reduces wear and metal-to-metal friction by separating parts with a thin film of oil, and it carries away excess heat. An oil supply of four to five quarts is carried in the engine's *crankcase* and pumped through the engine at a pressure of around 40 pounds per square inch.

The oil travels through passages to crankshaft bearings, camshaft bearings, timing gears, and valve gear. A controlled amount of oil is left on the cylinder walls by the *piston rings*. After traveling through the engine, the oil drains back into the crankcase, where it gives up heat before being pumped through the engine again. Some cars have extra oil coolers to aid this process.

COOLING SYSTEM

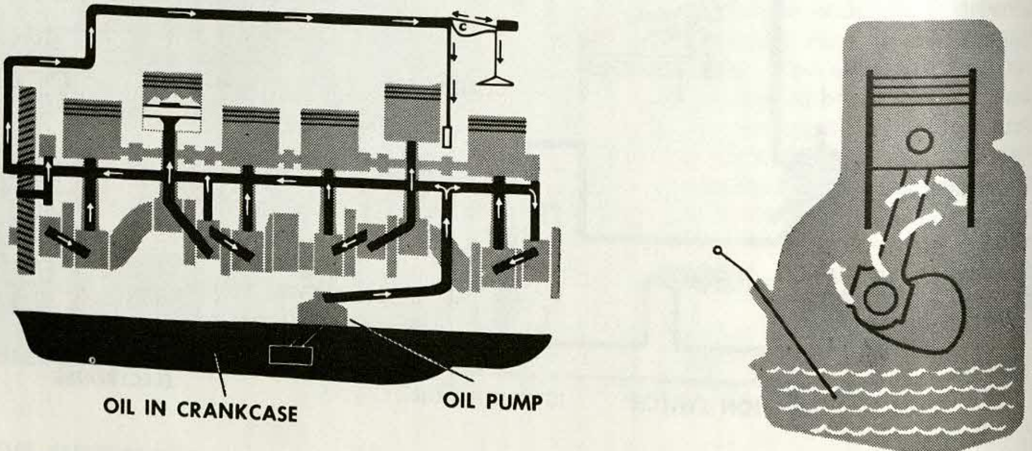
Much of the combustion heat is not turned into usable power, and an engine's cooling system removes this excess heat. Although some cars are air-cooled using blower fans, most are water-cooled. Water is not the correct term, actually, because the *coolant* is really a mixture of water and ethylene glycol. This chemical is used to keep the water from freezing in cold weather. The coolant also contains other chemicals to prevent corrosion and foaming.



Arrows indicate direction of water flow in this cooling system.

Coolant at low temperature is drawn from the bottom of a *radiator* mounted separately from the engine. An engine-driven *pump* helps this flow. The coolant travels through engine passages, absorbing heat as it goes. Then it is returned to the top of the radiator, where it gives off heat to the airstream passing through. A cooling *fan* aids this process.

The lubricating system of an automobile engine. Left: the pump forces the oil into various surfaces where it is needed. Right: the rotating action of the crankshaft causes oil to be splashed onto different engine surfaces.



EMISSION-CONTROL SYSTEM

The emission-control system reduces three harmful chemicals that accompany combustion. These are carbon monoxide, unburned hydrocarbons, and nitrogen oxides.

Hydrocarbons and carbon monoxide are by-products of burning fuel. To minimize these two pollutants, it is best to improve and continue the combustion process as long as possible. Continued combustion takes place in the exhaust system close to the engine. Often air is injected into the system to provide the extra oxygen needed for the added combustion.

Nitrogen oxides are formed whenever something is burned. More oxides are formed at higher temperatures. Exhaust gas recirculation (EGR) reduces nitrogen oxides by lowering ignition temperatures in the combustion chambers. This is done by mixing a portion of exhaust gas with the engine's fresh mixture of fuel and air.

An engine's output of these pollutants depends a lot on its fuel-air ratio. Controlling pollutants is complicated because engine tuning to a fuel-air ratio that gives low carbon monoxide and hydrocarbons also gives the most nitrogen oxides, and vice versa.

Catalytic conversion is another way to control pollutants. This uses precious metals acting as catalysts to help convert pollutants into less harmful substances. The catalyst is a material that increases the rate of chemical reaction. In a car, the catalytic converter is a canned package installed in the exhaust system ahead of the muffler. Converters are of three types: oxidizing, dual-bed, and three-way. An *oxidizing converter* uses a platinum catalyst to turn carbon monoxide and hydrocarbons into carbon dioxide and water. A *dual-bed converter* has an oxidizing unit behind another catalytic material, usually platinum and rhodium. The first unit turns nitrogen oxides into harmless nitrogen and carbon dioxide. The second unit oxidizes carbon monoxide and hydrocarbons. A *three-way converter* combines both types of catalysts into one unit, but it needs a very carefully controlled fuel-air mixture to work well. This system usually has an oxygen sensor in the exhaust pipe. The sensor is linked to electronic controls that stabilize the fuel-air mixture by adjusting the carburetor or fuel-injection system.

Catalyst materials can be poisoned by lead. Thus, unleaded gasoline is required in cars having catalytic converters. However, taking lead out of gasoline has caused other problems. Lead chemicals such as tetraethyl and tetramethyl lead are very good for preventing a harmful form of combustion known as *knock*. A gasoline's *octane rating* measures its antiknock protection, and octane ratings have gone down because of the elimination of lead.

Yet, catalytic conversion remains one of the better ways to reduce auto pollution. Unlike other control methods, it has little effect on fuel economy or performance.

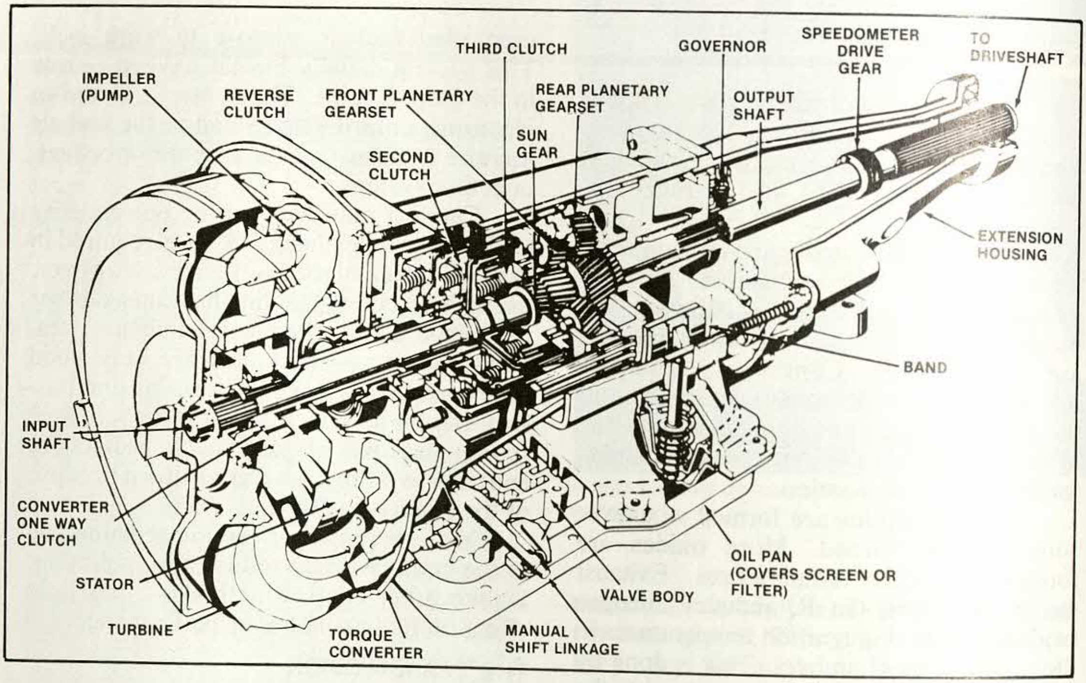
THE TRANSMISSION

A car's *transmission* and final drive take the engine's power, convert it to a useful speed range, and transfer it to the drive wheels. Gear ratios are chosen so that first gear is used to start from rest, intermediate gears are used for steady acceleration, and top gear gives fuel-efficient, quiet running at a steady cruising speed. Transmissions may be either manual or automatic.

A driver selects gears with a *manual transmission* through use of a *shift lever* and foot-operated *clutch*. The clutch links the gears to the engine's crankshaft and allows connection and disconnection of the two.

Manual transmissions have three, four, or five forward gears plus reverse. Each set of gears has the correct number of teeth to give the desired ratio of output-shaft speed to that of the engine. If, for instance, the ratio of teeth on the input gear to the output-shaft first gear is 3.5:1, this means the engine's crankshaft will turn 3.5 times for each revolution of the transmission output shaft when in first gear. Gear selection uses sliding forks operated by the driver's shift lever.

Some transmissions are direct-drive in top gear, with a sliding sleeve that locks



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A cutaway view of a typical automatic transmission shows the main components.

input and output shafts together. Others have overdrive top gears, that is, separate gear sets that give a ratio of less than 1:1.

With an *automatic transmission,* the choice of gear is not directly under driver control. It depends on engine speed, road speed, and load. Most modern automatic transmissions have two separate parts: a *torque converter* and a three- or four-speed *planetary gearbox*.

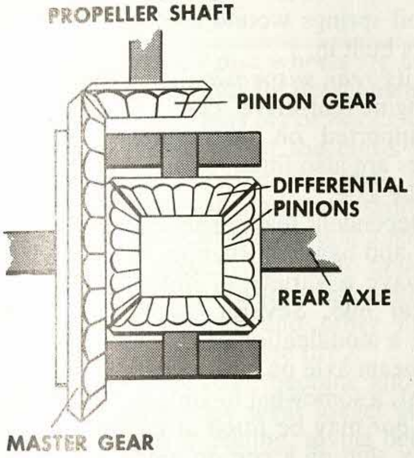
The torque converter serves two purposes. It acts as a clutch in cushioning the connection between the engine and transmission, and it increases the torque, or twisting force, sent to the output shaft. The torque converter is made up of a housing filled with hydraulic fluid and containing three pieces: an *impeller,* a *turbine,* and a *stator*. The impeller is connected to the engine's crankshaft and so it turns at engine speed. This movement creates a fluid flow within the housing that drives the turbine. The flow is made more powerful by the stator, which redirects the fluid. The turbine is connected by a shaft to the planetary gear set at the rear of the transmission.

When the driver places the control lever in "Drive," the impeller turns slowly at the engine's idle speed. This is barely fast enough to turn the turbine, and a light pressure on the brake pedal will hold the car in place. As the driver presses on the accelerator, the engine speed increases and this drives the impeller with greater force. The impeller in turn drives the turbine. Hydraulically operated clutches on the planetary gears bring about automatic shifts that depend on speed and load.

Because of its fluid drive, there is always some slipping in an automatic transmission. To reduce this, several modern designs have locking clutches that come into operation during some driving.

FINAL DRIVE

The routing of power from the transmission depends on whether the car is front- or rear-wheel drive. With rear-wheel drive, the transmission's output shaft is connected by *universal joints* and a *driveshaft* to the car's *final drive unit* at its rear axle. With front-wheel drive, the output



shaft is connected directly to the final-drive unit, often part of the same housing. From there, half shafts send the power to the front wheels through universal joints that allow the wheels to be steered as well.

In either case, the final-drive unit contains a device called a *differential*. This lets the car's two driving wheels rotate under power while following different arcs, the outer wheel traveling farther in a turn than the inner one.

Some cars have four-wheel drive. These combine systems similar to front- and rear-wheel drive. Some four-wheel-drive systems operate all of the time. Others are designed for driving in mud, sand, or dirt and allow two-wheel drive for ordinary conditions.

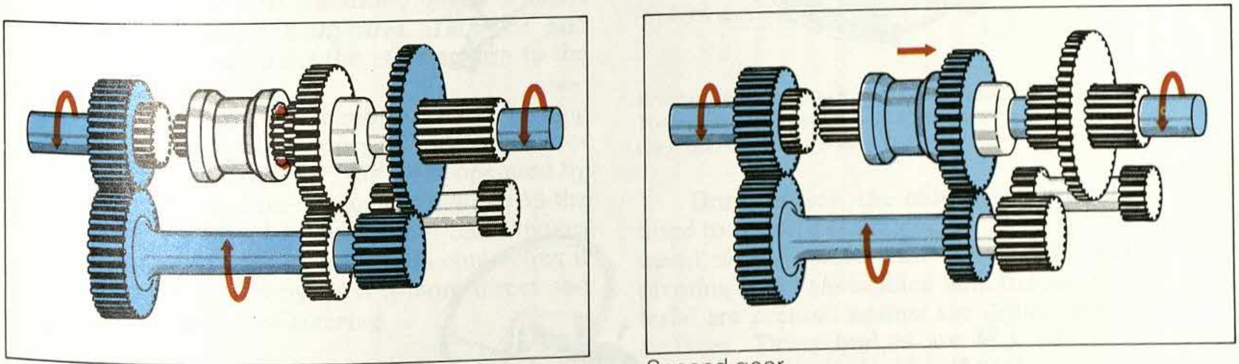
THE CHASSIS

A steel one-piece *chassis* and *body* are common for most modern cars. The chassis has places for engine mounts, suspension mounts, and attachment points for the bodywork's front fenders, doors, hood, and trunk lid.

As its name suggests, the *suspension* suspends the car from the road through its tires. Suspensions include locating links, springs, shock absorbers, wheels and tires, together with brakes and steering.

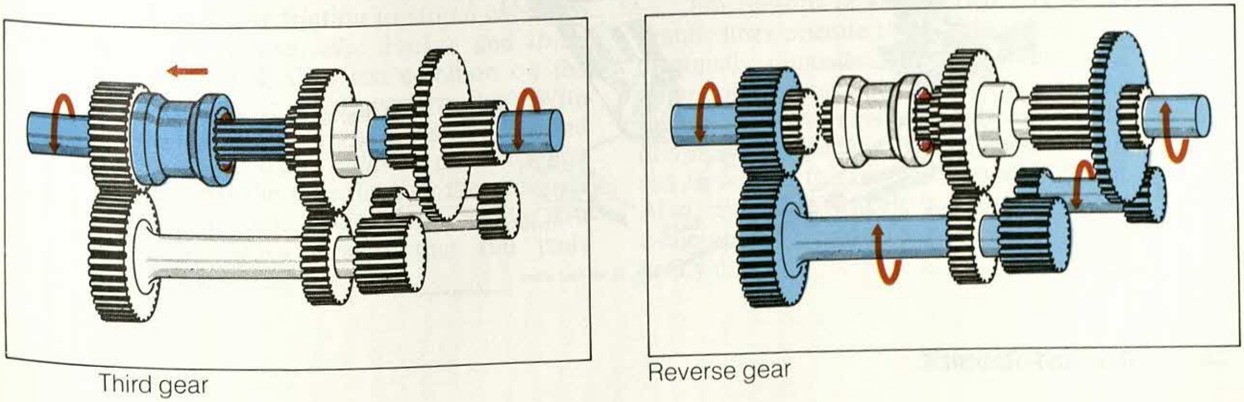
The *front suspension* of most modern cars is independent. This means that road

A manual, or standard, transmission, showing three forward gears and reverse. Some systems have as many as five forward gears.



First gear

Second gear



Third gear

Reverse gear

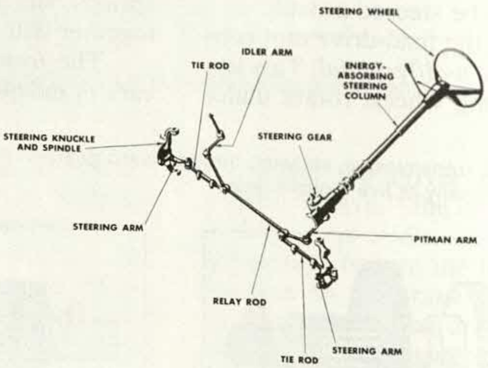
shocks of one wheel will not affect the other. Two types are common: *A-arms* and *MacPherson struts*. The first has each front wheel hub mounted on a pair of A-shaped arms attached to the chassis through rubber bushings. A coiled steel *spring* absorbs the shock of road bumps and a separate *shock absorber* keeps the spring from bouncing up and down in an uncontrolled way. Shock absorbers are also called "dampers," and this term gives a better description of their job: they damp the spring motions.

MacPherson struts are increasingly popular. Here each hub is attached to an angled strut, with the top of the strut connected to the chassis. The bottom is usually located by a lateral *link*. MacPherson struts have coil springs wound around them and dampers built in.

In its *rear suspension*, the traditional front-engine/rear-drive car has a "*live*" *axle* supported on coil or leaf springs. Dampers are also fitted, along with links to locate the axle.

Independent rear suspensions give better ride and handling than most live axles. These have a variety of links to position each rear hub. Several front-wheel-drive cars use a modification of this, with a lightweight beam axle on coil springs.

Last, a somewhat flexible bar called an *antiroll bar* may be fitted at either or both ends. By shifting a certain amount of load from the heavily loaded outside wheel in a turn, an antiroll bar reduces car lean.



A typical recirculating-ball type of steering system.

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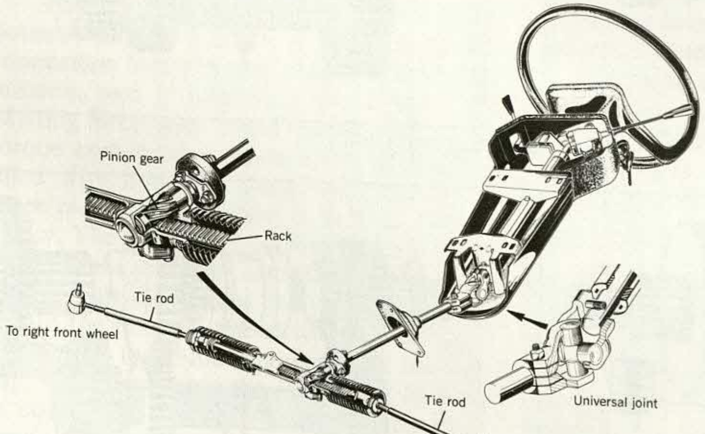


PEUGEOT MOTORS OF AMERICA

Parts of a rack-and-pinion type of steering system.

WHEELS AND TIRES

Steel or alloy disc wheels are mounted to the hubs with bolts for detachment. Tires are of two types: *bias ply* or *radial,* depending on the direction of the cords forming the tire structure under its tread. Bias-ply tires have cords wound on a slant; radial tires have their cords at a right angle to the direction of travel. Since the mid-1950's, most tires have been tubeless, with layers of synthetic rubber and other materials holding the air within the tire.

Radial tires have become almost universal because they wear longer and have less resistance in rolling, giving better fuel economy.

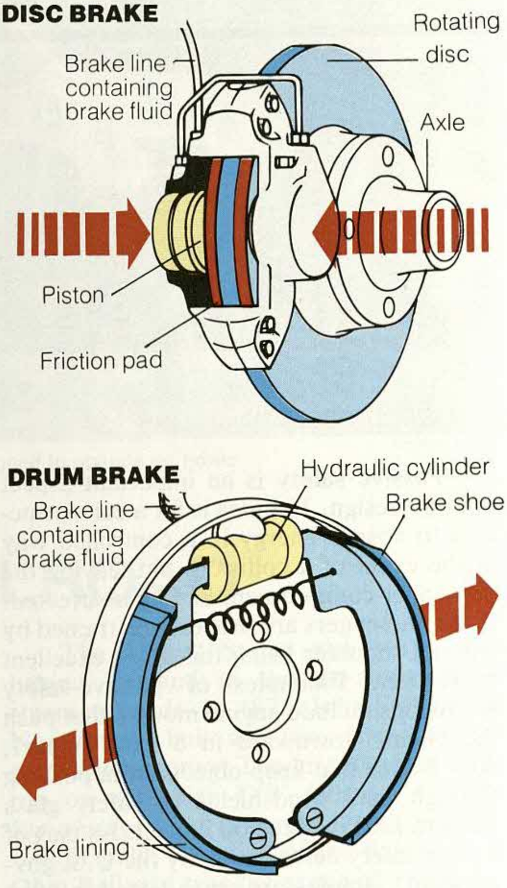
STEERING

Steering gear, part of the front suspension, lets the car's direction be changed. Two common types are *recirculating ball* and *rack-and-pinion*. With the first, rotation of the steering wheel turns a *worm gear* at the bottom of the *steering column.* This worm gear fits into a hollowed nut containing steel balls added to reduce friction. Movement of the nut turns a toothed sector, and this rotation moves a short *steering* (or *pitman*) *arm. Tie rods* and other links connect the steering arm to the wheel hubs.

With rack-and-pinion steering, turning the steering wheel gives a straight-line motion of a toothed bar, the *rack,* operated by a column-mounted gear, the *pinion*. As the steering wheel rotates, the rack moves back and forth, with tie rods connecting it to the wheel hubs. It is a more direct and sensitive type of steering.

BRAKES

Brakes use friction to stop a car. Two types are in use: *disc brakes* and *drum brakes*. Disc brakes are common on the front wheels of most modern cars. With these, a *disc* rotates with the wheel, and one or more fixed *calipers* press friction pads against the disc through the action of hydraulic pistons. The action is similar to a bicycle's caliper brakes that rub pads against the wheel rims.



Brakes are necessary for the proper stopping of a car. There are two types of brakes in use: the disk brake (top) and the drum brake (bottom).

Drum brakes, the older type, are still fitted to the rear of many cars. Here hollow metal *drums* rotate with the wheels, and pivoting *brake shoes* lined with friction material are pressed against the drums' inner surfaces. Drum brakes are less effective than disc brakes in giving off heat.

For reasons of safety, two sets of hydraulic lines operate the brakes, usually on diagonally opposite wheels. In this way, failure of one line will not cause total brake failure. Both systems are controlled by the driver's brake pedal, often with vacuum assist to reduce the required pedal pressure. Also, the rear wheels are fitted with a cable-operated brake for parking and emergency use.

The electric car has been proposed as an alternative to the fossil fuel-using automobile of today.

PASSENGER SAFETY

Passive safety is an important aspect of body design. The idea is for a car's structure to absorb energy in a controlled way in the event of a collision, but leaving the passenger compartment largely unaffected. If the passengers are properly restrained by lap and shoulder belts, this gives excellent protection. Examples of passive-safety provisions include engine mounts that push the engine downward in a front impact, door beams that keep objects from pushing through, and windshields of safety glass that are held in place on impact. As part of a car's safety certification by the U.S. government, samples are crash-tested in front and rear impacts at 48 kph.

Because many people do not understand the importance of using seat belts, passive means of restraint have also been developed. Passive belts, for instance, automatically secure a seated passenger, and protective air cushions, or "air bags," inflate automatically in the event of an impact.

FROM DESIGN TO PRODUCTION

Design, development, testing, certification, and manufacturing planning for a new car take about four years. Engineering studies, undertaken by specialists in each subsystem, begin long before any parts are made. While engineering work goes on, stylists sketch body designs, often in extreme "dream car" shapes, but still offering what the stylist sees as automotive beauty. Later, clay models are made in more practical shapes, and these are tested for aerodynamics in wind tunnels.

Finally, handmade prototypes are built. These are tested at automaker proving grounds and on public roads. They are often disguised to keep the design secret until introduction of the new model. During this time manufacturing engineers plan the new car's assembly.

Before an automobile reaches its final assembly point, each of its many parts and subsystems has gone from raw or partly finished form through many stages of machining, finishing, and subassembly. Much of this is done by robots operated by computers.

Final assembly brings all these subsystems together in an impressive display. The painted chassis/body begins its trip down the assembly line. Overhead cranes or floor-mounted conveyors move it along at a slow walking pace. Various parts are brought by other conveyors to workers at exactly the time they need them. At one location the engine is lowered from above; at another, suspensions are installed from below. Throughout the process quality-control inspectors check that specifications are met—and the automobile quickly takes shape.

The entire final assembly of an automobile takes no more than a few hours. In fact, since many cars are built one after the other, a car leaves the assembly line roughly once a minute. Yet, years of planning, development, and testing, and a great deal of talent go into production of a modern automobile.

General Motors

An electrically powered locomotive. This engine is designed to operate on power derived from overhead wires.

THE RAILROAD

Roads have been made and used by people since prehistoric times. They have ranged from the roughest trails to the broad super-highways. The problem has often been to provide a smooth, hard surface, so that wheeled vehicles could move easily.

When someone hit upon the idea of using rails, on which the wheels of wagons could roll, this meant that the friction between vehicle and road could be decreased considerably. It enabled man to move larger loads with far less energy than before.

HISTORY

Short railways, using wagons drawn by horses or oxen, were built in England and Europe as early as the sixteenth century, and later in the Americas. They hauled coal, stone, and ore from mines or quarries to nearby waterways. Their rails were of wood, or of wood capped with iron. Later they were made entirely of iron.

After the development of the practical steam engine in the eighteenth century, inventors tried to adapt it for motive power on the railroads. By 1804, an English engineer named Richard Trevithick had constructed a steam locomotive able to pull loaded mine cars. Public steam railroads first opened, in England, in 1825.

The United States was very close behind England in the development of steam railroads. In 1825, John Stevens, of New Jersey, built and ran a small experimental locomotive. The first locomotive to run on a regular U.S. railroad was the *Stourbridge Lion*, in Pennsylvania, in 1829.

In 1830, a section of the Baltimore & Ohio Railroad was the scene of a race between a horse-drawn vehicle and the *Tom Thumb*, a locomotive built by Peter Cooper, a U.S. ironmaster. Although the horse won, the railroad soon afterward adopted steam power. Also in 1830, regular scheduled train service began in the United States. The locomotive, the *Best Friend of Charleston*, hauled cars daily on the South Carolina Railroad.

From these beginnings, trains and railroads developed rapidly. Steam locomotives became larger, faster, and more powerful. They assumed their modern form—with a horizontal *boiler*, a *cab* for the engineer at the back, and a *smokestack* and a *pilot*, or "cowcatcher," at the front. Fuel—wood, then coal—was carried in a car, or *tender*, behind the locomotive.

The first cars were basically wooden wagons and stagecoaches fitted with grooved wheels to run on rails. Later in the

1800s, modern railroad cars took shape. Closed passenger cars, or *coaches*, had seats arranged along each side of a central aisle, which led to a platform at each end. *Boxcars*, *flatcars*, and *tank cars*, for freight, were not long in coming.

Various inventions made railroading safer. The telegraph and then the telephone aided in the control of trains. Automatic coupling replaced the primitive, hand-operated link-and-pin system of joining cars. *Air brakes* made for quicker and safer stops. In the modern air brake, compressed air keeps the brakes off. They are applied when the air pressure is decreased and thus stop the train.

The flimsy wood or iron rails of the early lines were eventually replaced with heavy steel rails. A standard gauge, or track width, was widely adopted toward the end of the nineteenth century.

Other innovations came: refrigerator cars, to carry food and other perishables long distances; steel cars; electrified systems for signaling and other communications. Later on came electric and diesel locomotives, and many others. With the standardization of time zones, long-distance train scheduling became much easier.

Railroad construction boomed during the nineteenth century. In England, the United States, and Canada especially, the increase in the amount of usable track over the decades was phenomenal. For example, the United States in 1860, on the eve of the Civil War, already had 48,000 kilometers of track, most of it east of the Mississippi River. By 1869, the east and west coasts were linked by the first transcontinental line. Canada completed its first transcontinental railroad in 1885. Somewhat later, Siberia was crossed by a railroad. Today the world has more than 1,000,000 kilometers of track.

Railroads have had their ups and downs. Before the coming of the automobile, they were the only form of mechanical land transportation. But with the perfection of autos and airplanes, railroads suffered. Though trains remained an important means of hauling freight, they greatly cut passenger service. Now, because of a fuel shortage, it is possible that trains will again become a favored means of transport, since they are much more efficient than cars and planes in the use of energy.

Association of American Railroads

Diesel-electric locomotives such as this one are common wherever there are railroads.

TYPES OF LOCOMOTIVES

Steam locomotives. Basically, the *steam locomotive* is nothing but a self-propelled steam engine. Water in a boiler is heated by coal or oil burning in a firebox. The resulting steam pushes against pistons in cylinders. As the pistons move, they turn the wheels of the locomotive.

Electric locomotives. For many years, the steam-powered locomotive was the king of the rails. But since 1945 it has largely been replaced by electric and diesel engines.

Electric power for railroads was tried as early as 1842, when a battery-operated locomotive was developed in Scotland. But another type of electric locomotive—one that used an external power supply—became important. It went into regular service in the United States in 1895.

Power for these electric engines passes from a central generating plant either through a third rail on the ground or along overhead wires. The locomotive, which does not have its own source of energy, picks up the electric current through a metal shoe sliding on the *third rail*. Others pick up power from the overhead wires through a device called a *pantograph* atop the locomotive.

Because the trains draw power directly from an external electrical source, fumes are not a problem with electric trains. For this reason and others, many kilometers of electrified track have been lain below ground level. Trains run through tunnels and pick up or discharge passengers at underground—or in some cases, aboveground—stations. These systems, called *subways*, *undergrounds*, *metros*, and various other names, are used to provide mass transportation in congested urban areas. By placing these systems underground, there is less congestion at ground level. Also, the need for unsightly elevated tracks is eliminated.

Diesel locomotives. ***Diesel-electric locomotives*** have replaced the steam locomotive on practically all lines. The diesel-electric does not depend on a distant generating station for its power. It contains a diesel oil-burning engine that drives an electrical generator. The electricity turns the wheels and also operates lighting and often heating systems on the train.

Lightweight diesel-electric locomotives built in the 1970s can attain speeds as fast as 165 kilometers per hour.

The *diesel-hydraulic*, a near-relative of the diesel-electric, substitutes a hydraulic, or fluid transmission, system for the electric one. Although this locomotive is more compact than the diesel-electric, it requires complex gearing for drive.

For pulling huge loads long distances at high speeds, the *gas-turbine-electric locomotive* is ideal. Here, an oil-fired jet-type engine spins a turbine, which operates an electrical generator for motive power. This type of locomotive is only in limited service.

PASSENGER TRAINS

Passenger-carrying trains making short runs with many stops are called *locals*. *Expresses* make long runs and few stops, usually at the larger cities and towns. Passenger trains often carry baggage, mail, and other delivery items.

A *coach* is the most inexpensive method of passenger-train travel. Only fixed seats are provided for the passenger to sit and sleep on. For those preferring more comfort, *parlor*, or *chair*, *cars* are available. They have individual, movable chairs.

Sleeping cars are best for overnight trips or those taking more than a day. Various accommodations are available, from upper and lower berths to private rooms with beds and other comforts.

Dining and lounge cars serve food to passengers. On long trips, passengers can move into an observation car, at the end of the train. There they can view the scenery through wide windows. *Dome cars*, each one having a glass cupola for sightseeing, serve as dining, lounge, or sleeping cars.

From time to time, lightweight, streamlined trains with low centers of gravity have provided passengers with high-speed service in air-conditioned comfort. Such trains are becoming more common in some areas. They may use novel means of propulsion, such as magnetic suspension or a compressed-air cushion.

Amtrak, the U.S. National Railroad Passenger Corporation, uses turbotrains, powered by gas turbines. The trains can reach speeds of 270 kilometers an hour on a good track.

Amtrak

FREIGHT TRAINS

Railroads have a great variety of cars in which to transport different kinds of goods. Perhaps the most familiar is the *boxcar*, which is completely enclosed with sides and a roof. It carries products that must be protected from the weather or from theft. A *stockcar* is a boxcar with slatted sides, to allow air for the animals inside. A *refrigerator car* is a boxcar chilled by means of ice or a machine, to preserve perishable items.

For carrying huge, heavy, but durable loads, *gondolas* are employed. These are cars with low sides and no top. *Hopper cars* carry coal and ore. They have high sides and an open top and may be tippable to release their loads. Some hopper cars are roofed in, but are provided with hatches for loading and unloading.

Flatcars are simply open platforms on wheels, with no sides or top. They can carry large loads, particularly trucks, trailers, and wheelless containers. This service eliminates the need for unloading the contents of trucks, trailers, or containers at a railroad station and then reloading the contents at the destination.

Another type of car is the *multilevel rack*, for transporting new automobiles and trucks from manufacturer to dealer. A triple-deck rack car can carry fifteen vehicles.

Tank cars, some insulated like vacuum bottles, move oil, gasoline, liquid chemicals, or beverages. Large ones may have a capacity of 114,000 liters each.

Loaded freight and tank cars are often sent from one railroad to another before they arrive at their final destinations. This is why we often see cars of different lines joined together in one train. But a unit train carries a single commodity, or various commodities in containers, between two points in one run, without yarding and switching of cars.

At the end of a freight train is a closed car called a *caboose*. It serves both as quarters for the crew and as an observation post for monitoring the train.

RAILROAD EQUIPMENT

Railroads have many different kinds of cars and machines with which to construct and maintain their lines. They include cranes, derricks, steam shovels, pile drivers, rail unloaders, various track maintainers, supply cars, and snowplows.

But the total property of railroads goes far beyond these. There are the rights-of-way, or the land occupied by the tracks; tracks; signals; embankments; tunnels; bridges; switches; stations; yards; dock and port facilities; repair and maintenance shops; telephone, telegraph, and power lines; radio, television, and radar; and others.

The track is the very basis of the railroad line. It consists of parallel rails laid at right angles to crossties which are wooden or concrete, on a roadbed of gravel, or

Japanese National Railways

The Japanese National Railways has developed this miniature high-speed train. When moving it actually hovers over the track. Special superconducting metals in the train are magnetically repelled by the track, keeping the train a little bit above the surface.

ballast. The standard steel rail is shaped like the letter T, resting on a wide base, or *flange.* The rail sections are bolted or welded together.

As trains run along the tracks, their movements are guided with electrically operated signals placed alongside the rails or overhead. These *fixed*, or *wayside, signals* divide the right-of-way into sections, called *blocks.* As a train enters a block, it automatically sets the signals in that block to indicate "stop" to any following trains. The signals in the block behind the one in which this train is running often indicate "caution" or "slow" to a following train. When the train is a long distance from a block, the signals there read "track clear" again.

The signals may be in the form of colored lights or swinging arms, called *semaphores.* On some railroads, the same types of signal lights are located on a panel in the cab of the locomotive. They are activated by electric current passing from the tracks into the locomotive.

If a train has to move onto a different track, it is shunted by means of a switch. This is a device that shifts movable rails at points where different tracks separate or come together. Switches may be operated directly by hand or by remote control through motors. Switches are often located in yards, stations, and junction points.

In the so-called *interlocking system*, tracks and switches at a given location are set and locked against all but one train movement at a time. This system is often applied at terminals and junctions, where trains are constantly being rerouted. The controls are interlocked in such a way that, unless an established procedure is followed, no switches can be thrown.

Another system of handling train travel is *centralized traffic control*, or *CTC.* Here the movements of trains over many kilometers of track are electrically controlled by an operator from a central board, or panel. CTC allows the operator to signal any train crew and give them instructions. He can also contact a train by radio or telephone. Computers have now been applied to the dispatching of trains also.

Chesapeake & Ohio Railway

At work in the nerve center of a modern freight-car classification yard. Computers direct the classification and movement of cars, under the watchful eye of a yardman at a monitor.

SOPHISTICATED TRAINS

A train may be able to identify itself automatically by means of a tuned coil it carries. As this coil passes through the fields or fixed coils at wayside stations, the train automatically lines up its own routes through various interlockings.

Railroad communication, from station to station, from train to train, and from train to station and vice versa, is highly sophisticated today. Telephone, telegraph, and radio are used. Radar is also important, especially in train floats and ferries. Television monitors the sorting of freight cars in yards and traffic conditions on the rails. It also watches track-highway crossings and sounds warnings whenever necessary.

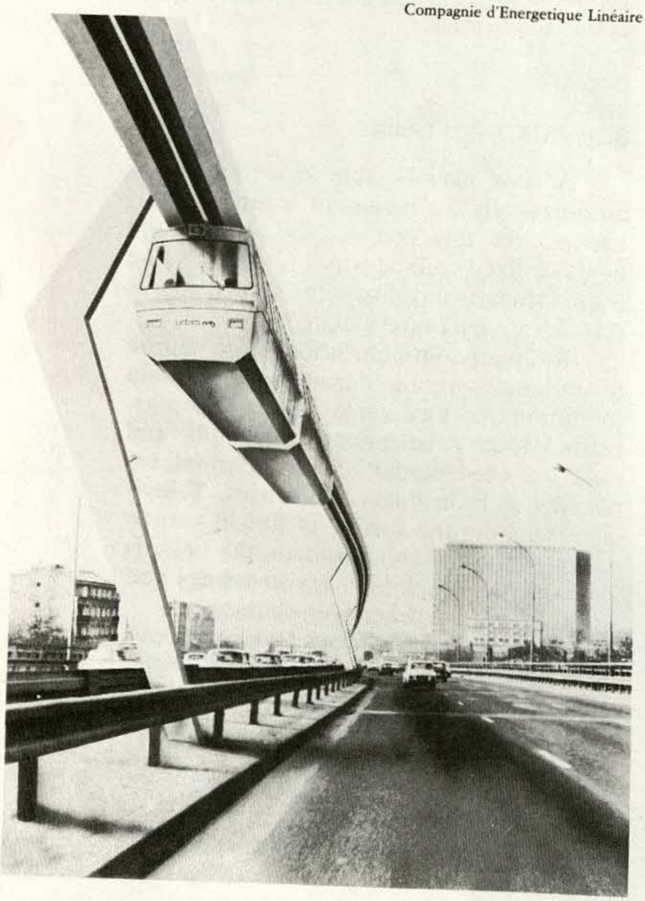
With all the advances outlined above and the great possibilities of new technology, many authorities foresee a time when trains will again become prime movers of passengers. Trains produce less pollution than do automobiles and airplanes. They use less fuel to carry passengers and freight. And their tracks use less land than do roads.

URBAN MASS TRANSPORTATION

by Forrest E. Harding

As the dawn of civilization pierced the darkness of man's primitive state of existence, the foundations of city life began to emerge. Created out of a common need, human communities slowly developed. Here, altars were constructed, fortresses were built, and markets for the exchange of goods evolved. The beginnings of government took shape.

The first of these early cities appeared about 4000 B.C. in what is now the nation of Iraq. Later urban centers arose in the great valley of the Nile River, in Egypt, between 3000 and 2000 B.C. All were communities of modest size, each having 5,000 to 20,000 inhabitants.



URBA: a form of mass transit. In this French project, the train hangs by suction from an overhead rail. It is propelled by a motor system that has no moving parts.

Compagnie d'Energetique Linéaire

These early centers of civilization eventually led to the rise of the Greek city-state and the great city of Rome itself. At the peak of its power, under the Roman Empire from the first century B.C. to the fifth century A.D., Rome was the home of more than 1,000,000 people. It was the largest urban center in Europe before the coming of the present industrial age. Like many a modern city, Rome was plagued with traffic problems. To ease the congestion, Julius Caesar barred the use of the streets to freight wagons during daylight hours.

An interesting similarity between ancient cities and the urban centers of little more than a century ago is that all people either walked or were conveyed by horses or other draft animals or even by other human beings. Obviously, travel was highly limited. Until the last quarter of the nineteenth century, therefore, cities radiated only some three to five kilometers outward from their political and economic centers. Each one could reach a maximum area of only about 50 square kilometers. Within these boundaries, however, population densities equaled those of many of today's cities.

Had you lived then, what would you have seen? First, you would have noted that virtually all the important jobs were located in the center of the city. Second, you would have observed concentric circles of residences surrounding this working urban core. In fact, as recently as 1890 you would have noticed streams of workers, three or four kilometers long, trudging from their homes to their jobs in the centers of major cities.

The mechanization of transportation and industry set the stage for the vast metropolitan areas many of us know today. With a roar, a hiss, and a whistle, the newly invented steam locomotive revolutionized land transportation.

Although it was intended largely for intercity and cross-country travel, the steam train was at first the only mechanical transportation available to city dwellers. Ribbons of steel track soon tied urban populations to the economic hubs of the growing cities.

During the latter half of the nineteenth century, however, electricity was applied to urban transportation. In 1884 the first commercially operated electric railway was established, in Cleveland, Ohio. Afterward, many other cities adopted this type of transportation system.

Some communities raised the tracks of their steam- or electrically-powered trains above the streets. Except for those in New York and Chicago, these elevated railroads, or "els," were unpopular. The reasons were their high cost of construction, their noise, and their unsightliness. In recent decades, most of these old "els" have been torn down.

Other municipalities dug tunnels underneath the streets for their railroads. The earliest ones, such as the London Underground, were run with steam locomotives. Later, underground railways, or *subways*, were electrified, which made for cleaner, faster, and quieter operation.

Electric trolleys became common about the end of the nineteenth century. Previously, trolleys had been pulled along tracks on city streets by horses. These so-called *horsecars* had served well, but they were very slow and could no longer meet the needs of vast cities with exploding populations. Electric trolleys were often powered by contacts on overhead wires. Soon networks of tracks and overhead wires radiated outward from metropolitan centers. Many trolley lines, however, have been replaced over the years by buses and subways.

All these early forms of mechanized transportation allowed much greater flexibility in the establishment of homes in municipal areas. City people now had the choice of living up to eight kilometers from the center, or downtown part, of the city. As a result, in the early years of the twentieth century, the typical large North American or European city covered up to 200, instead of only 50, square kilometers.

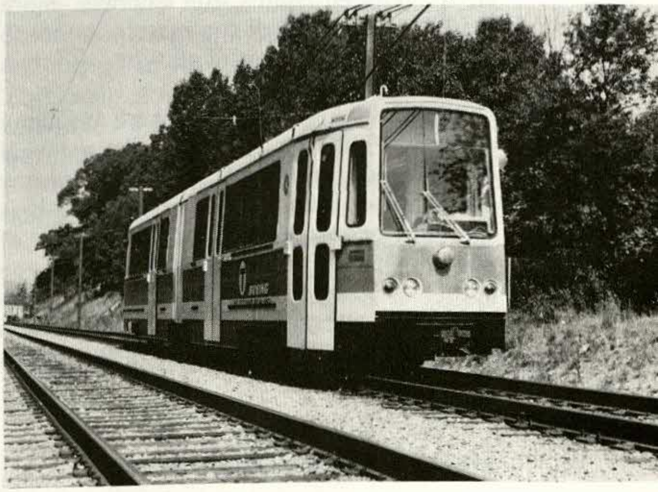
Often, much of the new residential zones was "suburban" in character and served by long subway, train, "el," or trolley lines. From these beginnings, urbanization grew rapidly. By 1920, industrialized nations like the United States had more people living in towns and cities than in country, or rural, areas.

Recent census figures show that this urbanization process has become extreme. Over two thirds of North Americans now live in regions designated as metropolitan, because of the high density of their population and housing. Of these people, more than half live in suburbs rather than within a so-called "inner city," or original urban core. In recent decades, suburban communities have grown by over 25 per cent in the United States and Canada.

In contrast, some of the largest cities in the United States either have not increased in population during this time or have actually lost people. In twentieth-century North America, the population has been decentralized into vast metropolitan complexes.

A Light Rail Vehicle, or LRV, being tested as a means of urban transportation. The system runs on power from overhead wires.

Boeing Photo



THE AUTOMOBILE

What about this latest metropolitan decentralization? Is it also related to transportation? The answer is yes. Decentralization has been drastically increased by the advent of the automobile.

Many experts do not consider the automobile to be a form of mass, public transportation, as trains and buses are. The auto is essentially a private vehicle, even when it is a taxi. Nevertheless, the car has become an almost universal means of movement for many millions of people. In some cities, such as Los Angeles, California, it is about the only mechanical transportation available. In still other cities, the auto and the highway are in such strong competition with the bus and the train that they have nearly crippled the successful operation of all these public mass carriers.

How did this situation come about? When Ransom Olds wheeled his homemade motorcar out of his father's shop early one morning in 1887, he could hardly have realized the impact it would have on the lives of coming generations. A competitor of his, Henry Ford, later developed the assembly line, which put the automobile within the reach of almost every working person living in the United States. Not even Henry Ford would have dreamed of a time when more than 100,000,000 automobiles would pack the highways of North America.

If you have ever been caught in a traffic jam, perhaps you have suspected or realized that the automobile is the most popular form of urban transportation today. In the United States, for example, more than 75 per cent of all commuters choose to drive, and 90 per cent of all types of urban travel is by car.

Why is this the case? There are many reasons. First, the auto is a great personal convenience, in many instances permitting door-to-door transportation. Second, it is for many people a status symbol—a sign of power, wealth, and speed. And third, the automobile provides almost unlimited mobility for young and old alike. Jumping in behind the wheel of a car is the ultimate in freedom to numerous drivers—the ability to go anywhere a road may take one and to flee one's problems, at least for a time.

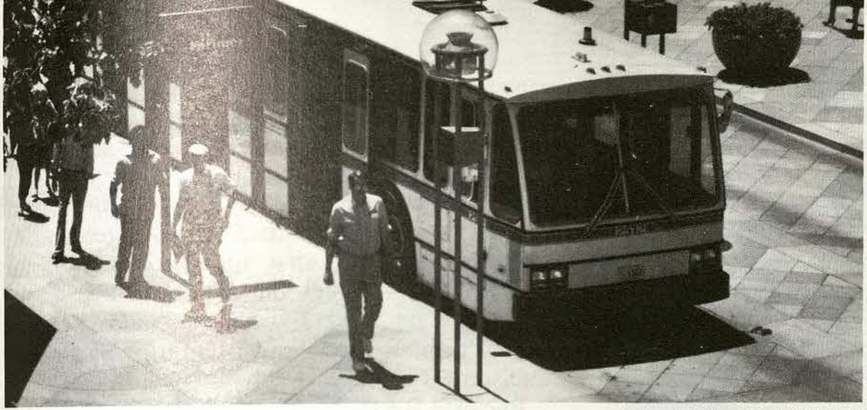
With the coming of the cheap motorcar in the early 1900s, the demand for new and improved streets and roads began to grow. Beginning in 1916, the United States federal government helped finance highway construction on an ever-widening scale, from the local to the interstate level. Similar progress took place in Canada, especially after 1945, although provincial governments were largely responsible.

This tremendous highway expansion ultimately led to the great urban decentralization of today. Once limited-access roadways were completed in metropolitan areas, the flight of inner-city residents to the suburbs was on in earnest. People could now commute much greater distances than ever before between home and job.

It is possible to overdo a good thing. Today we suffer from many automobile-related problems: massive traffic jams; pollution of the air by auto exhaust; noise; overuse of land for parking lots and garages; and death and injury in automobile accidents. Superhighways spiderweb over the landscape, uprooting entire communities. "Good" roads deposit millions of additional people in already congested downtown areas, and in parks, on beaches, and at other recreation areas. The city of Los Angeles devotes 85 per cent of its downtown land to the use and care of automobiles, yet it is still congested. And the costs of highway construction have become staggering—as much as $60,000,000 per kilometer. Yet governments continue to make gigantic outlays for more road construction.

Automobiles consume vast quantities of the world's oil resources as gasoline. Gasoline shortages are already troubling the United States and other industrialized nations, which must import much of their petroleum. Automobiles are thus one of the prime causes of the energy crisis spreading in many areas of the globe.

Difficult to measure exactly is the social cost of the massive growth of autos and highways. How do we measure the fall



To eliminate automobile congestion and reduce air pollution, transportation in this urban mall is limited to buses.

© Stewart M. Green/Tom Stack & Assoc.

in job performance brought on by the daily traffic "battle" on the freeways? How do we estimate the impact of the isolation of neighborhoods by a maze of superhighways that are impossible to cross on foot? How many lower-income people are unable to find or hold jobs because they cannot afford a car and there is no public mass transportation available? And how do we help people evicted from their homes by the mushrooming construction of highways?

DECLINE OF PUBLIC TRANSPORTATION

In spite of the objections discussed above, many authorities still insist the automobile is the best answer to our transportation problems. But a growing number of experts, and of ordinary citizens as well, are demanding bigger and better public transit facilities to offset the effects of the automobile. As the popularity of the automobile has zoomed, however, urban mass-transit systems have been allowed to deteriorate, particularly since the mid-1940s. This has happened despite a sharp rise in urban population. In North America, mass transportation in cities has lagged behind population growth and has generally become outmoded, unpleasant, ineffective, and even dangerous.

Three critical factors have contributed most to the decline of public mass transportation: (1) enormous increases in the cost of operation; (2) a steep drop in the number of passengers and, therefore, in transit revenues; and (3) uneven, inefficient use of the vehicles, with full loads during morning and evening rush hours only. We may add the fear of crimes committed in many urban transit facilities.

ADVANTAGES OF PUBLIC TRANSPORTATION

Mass transportation offers many advantages to the dwellers, commuters, and visitors in a metropolitan region. Congestion of streets and roads is lessened because, except for buses, mass-transit vehicles usually have their own rights-of-way. Buses may be excused, since each one carries far more passengers, for its size and weight, than the three average automobiles it displaces from the road.

In addition, public transportation helps conserve dwindling fuel supplies. At the same time, it reduces air pollution. The chief reason is its basic efficiency as a mass carrier, using less vehicles and fuel per passenger. Also, certain mass-transit vehicles are powered by clean agents, such as electricity or nonpolluting natural gas. The increased use of mass-transit facilities should also help cut down on auto traffic, with its waste of fuel and its pollution of the atmosphere.

In many communities, however, moves are under way to make the auto more of a mass carrier than it ordinarily is. Car pools are being organized. In these, each private automobile takes a full load of passengers to work and back home again. This is intended to decrease traffic flow and save on fuel and costs. Car pools are working with some degree of success in a number of cities, and their use is on the upswing. They are being encouraged by reductions in tolls offered to cars carrying full loads of passengers. Some authorities claim that carpool costs average lower for many commuters than fares on bus or railroad lines. Other people are pushing for

The trains of Mexico City's subway system have rubber tires, which give commuters a quiet, vibration-free ride.

U. Bernatii—Photo Trends

taxis to carry more passengers to various destinations, not unlike the car pool. They see this as a way to offset the plans of some city authorities to ban private cars and cruising taxis entirely from downtown areas.

In the long run, however, mass-transportation fares are generally lower than the cost of operating a private car over the same distance under the same conditions. In addition to the expense of gasoline, oil, and tires, automobile owners must include the costs of maintenance, repair, insurance, depreciation, license fees, and parking and toll charges in their calculations.

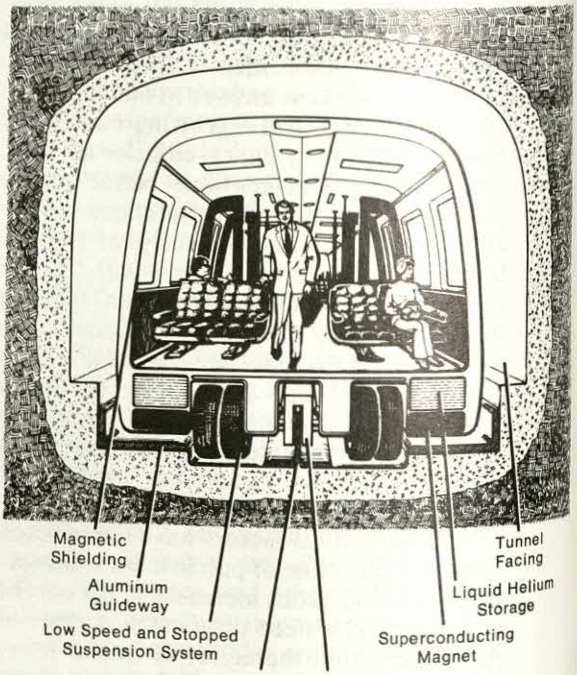
NEW FORMS OF MASS TRANSPORTATION

Solid public support, both in the form of money and of willingness to use mass transit, will be needed to restore public transportation in the cities. Furthermore, new ideas and technical advances will be necessary if the overwhelming preference for the family car is to be overcome.

Computer technology is one of the new tools that can be used to help solve current mass-transportation problems. A good example is found in the San Francisco–Oakland metropolitan area. In September 1972, after almost fifteen years of planning and construction, the Bay Area Rapid Transit System (BART) began service between Oakland and Fremont, California. BART has been heralded as the model for future public transportation systems in other cities. It is fast, comfortable, and efficient. Passengers enjoy a smooth and quiet ride at speeds up to 130 kilometers per hour in carpeted, air-conditioned comfort. The trains travel on a right-of-way apart from city streets, which includes a series of tunnels along the bottom of San Francisco Bay.

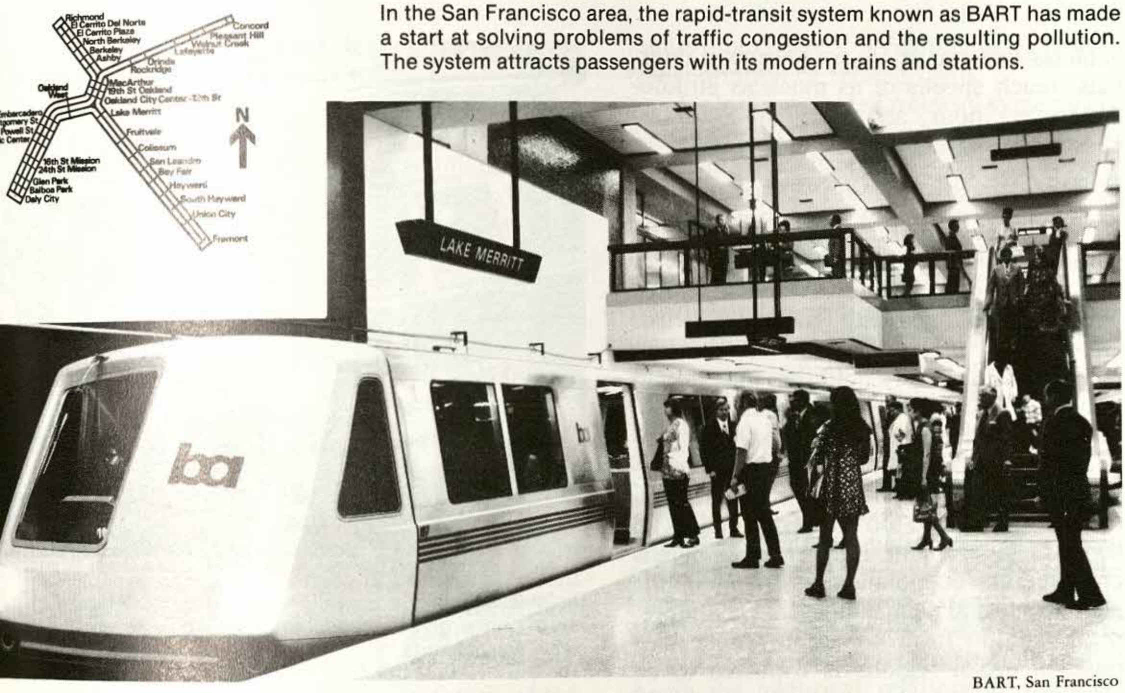
Because BART is required by its character to pay its own way, efficiency of operation has been a major goal of its planners. A central computer controls the system, guiding trains, making routing decisions, and even handling tickets. As a result, far fewer people are needed to run the entire operation—an immense saving in labor costs.

Another application of computer technology to public transportation is being tested in certain communities throughout the United States and Canada. This is the



Stanford Research Institute

Magnetically operated train. A linear induction motor with liquid helium-cooled supermagnets produces electric current in the rail. The current draws the train along swiftly.



In the San Francisco area, the rapid-transit system known as BART has made a start at solving problems of traffic congestion and the resulting pollution. The system attracts passengers with its modern trains and stations.

BART, San Francisco

Dial-a-Bus system. An automatic vehicle computer keeps track of all buses; their locations, speeds, destinations, and number of seats available. A centralized telephone network accepts calls from potential passengers. The locations of these would-be passengers are fed into the computer described above. It then plots their positions, selects the nearest buses, and dispatches them to the homes of the callers or to convenient bus stops. Mathematical formulas are used to handle the buses so that maximum efficiency is ensured.

Dial-a-Bus systems have proven popular in test situations in the United States and Canada. They have been very successful as both primary transportation and as feeders to commuter rail systems. Costs for the individual commuter are considerably less than for transportation by personal automobile, and energy savings are significant. The systems are expected to spread to many cities.

Another group of automated, personalized mass-transit systems under development is called People Movers, Personal Mass Transit (PMT), or Automated Mass Transit (AMT). They all operate like huge, but horizontal, elevators. They will use their own rights-of-way, with compact, 12- to 20-passenger vehicles.

Imagine walking onto a boarding platform and pushing a button, much as you would summon an elevator. The pushed button would activate a central computer, which would inform an appropriate vehicle of your location and direct it there. Each vehicle would receive such electronic messages from the computer through a transmission line built into the guideway. When the designated vehicle reached its assigned point, it would automatically pull off the main guideway and stop to let you on board. Once again, as in an elevator, you would push a button, to establish your destination in the computer's memory bank. The vehicle would then take you there.

A similar, intermediate-capacity urban transportation system is planned in Ontario, Canada, for major cities. It will operate on guideways at or above ground level. Such a system can also use established rights-of-way, such as water tunnels or the medians of divided highways. The vehicles will run at 15- to 20-second intervals, reach speeds of as much as 80 kilometers per hour, and carry up to 20,000 passengers per hour in one direction.

Ford Motor Co.—Ann Arbor Transportation Authority

Dial-a-Bus system in operation. Passengers call the bus by phone, give their locations, and are picked up by an available bus.

FUTURE OF THE AUTOMOBILE

Some pessimistic experts feel that the automobile is doomed. They see a day in the not-too-distant future when all autos will be abandoned and allowed to rust. Other authorities, however, think the auto is here to stay. They hold that the car will remain a leading means of urban travel in the foreseeable future. These experts maintain that rapid-transit systems are expensive to build and operate, take time to construct, and require too much planning at all levels of government. Furthermore, there is considerable economic investment in the automobile and its manufacture. Therefore, the evolution from private to public carriage in urban regions is expected to be slow.

The motorcar will undoubtedly change significantly. It should become smaller, safer, and more economical, and should be powered by alternatives to the gasoline internal-combustion engine. The car of the future should be far more pollution-free than present types.

Several new types of automobile engines have been developed. The Wankel rotary engine burns gasoline to power a rotating element inside a chamber, instead of an up-and-down-moving piston in a cylinder, as in the conventional engine. The result is a simpler design with a superior power-to-weight ratio. Used commercially in the Japanese Mazda automobile, it showed no great advantages, however, and was not sold in the United States after the mid-1970's.

The stratified-charge gasoline engine features a small extra combustion chamber and a double-barreled carburetor. The carburetor feeds a rich fuel mixture into the small chamber. This mixture burns, and in turn ignites a lean fuel mixture, which enters a larger combustion chamber. The rich fuel burn is not simply exhausted into the outside air; excess fuel is held in the small chamber for the next burn. The engine was introduced by Honda in 1972, and, although it offered economy and reduced pollution, it failed to gain general acceptance.

In the gas-turbine engine, hot gases create thrust through a set of turbine blades, which rotate a drive shaft. Expensive to build and heavy users of fuel, turbine engines have performed well in racing cars.

Electricity is a smooth, quiet, pollution-free source of automotive power. But electric vehicles, other than trains, will not be truly practical until a powerful, compact battery or other dependable source of current is available. Otherwise, electric cars will remain comparatively slow and require frequent stops to recharge their batteries.

Steam engines have been adapted for modern vehicles. They feature a closed system that heats water to make steam to drive a turbine or piston. The used steam is condensed and recycled through the system. The steam engine is cumbersome for private autos, although designers claim they have developed suitable types. The enormous advantage of the steam engine lies in its cheap fuel, absence of polluting emissions, smoothness of operation, and direct power without the need for gears or other forms of transmission. It should be ideal for trucks and buses.

Regardless of its power source, the auto is the main problem in urban traffic congestion. One proposed solution to this problem is the automated freeway system. Automobiles here will operate on their own power only long enough to reach the nearest entrance ramp leading to a freeway. Before entering the major traffic flow, the driver will insert a credit card into a device that will then check him into the system. It will also determine the base for highway tolls, if there are any.

When the auto enters the freeway system, a retractable arm will drop from the auto and make contact with a rail that is similar to those powering elevated and subway trains electrically. Once attached to the rail, the car will become electrically powered from the system, and control of the vehicle will pass to a central computer. The computer will then monitor all of the car's movements.

The driver will use a telephone to dial instructions about his destination into the system. The computer will calculate the best route, and reserve space for the car all the way to the correct exit from the freeway. The driver will then be free to relax and wait for the buzzer that will warn him of his coming exit. When his destination is reached, the driver will leave the car at a designated spot. Since he does not own the car, but only rents it, it will be used by another person. It is estimated that an automated freeway will be able to handle 10,000 vehicles per hour, compared with the 1,500 to 2,000 vehicles that can be carried by a present-day freeway.

THE 21st CENTURY

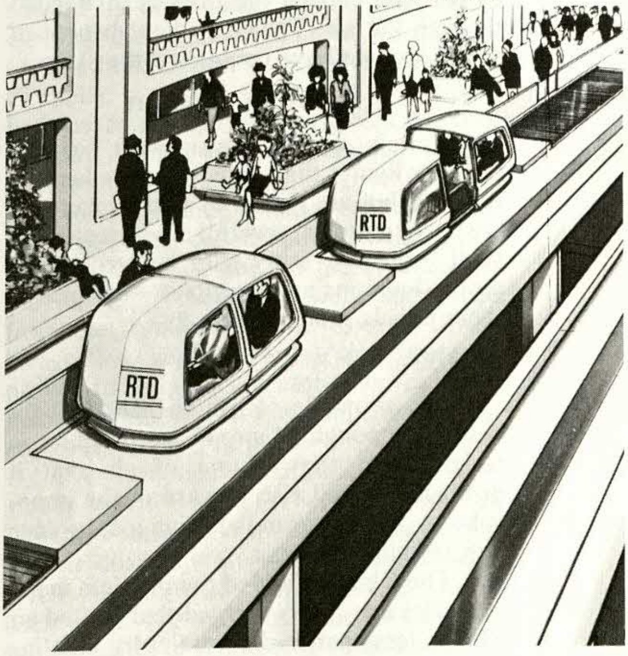
Urban transportation is in a period of marked change. We are breaking many of our ties to the technology of our forefathers and are reaching for new solutions to city transit problems. Not only are these problems technologically complex, but politically, economically, and socially complex as well. We should not expect revolutionary solutions to these problems. Rather, a long period of evolutionary change may follow, unless unexpected developments occur in transportation or related fields.

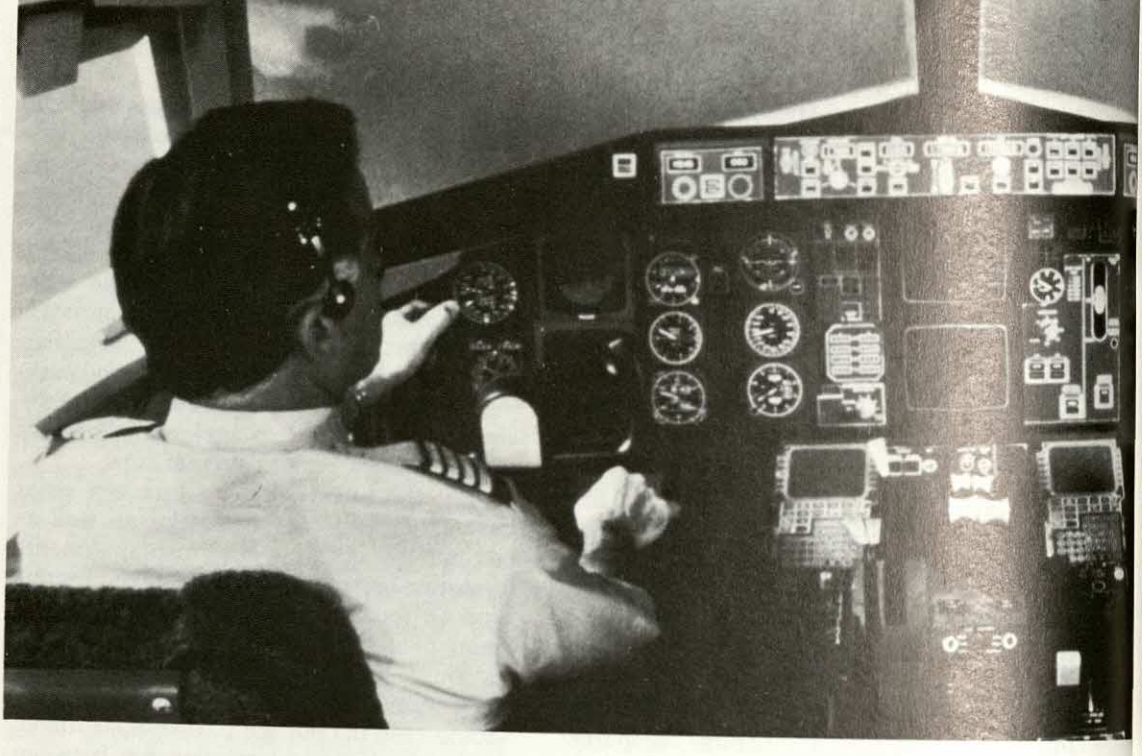
Unless automated freeway systems are widely adopted, the dominance of the automobile will disappear or become lessened. It may be replaced to a large extent, perhaps, by novel forms of public mass transportation. The decline of the auto will also be forced by fuel shortages, laws barring it from the cores of our cities, and parking restrictions. Commuters and other travelers will then have to seek other kinds of transportation besides private cars.

In the twenty-first century our cities may again become residential as well as commercial centers. High-rise apartments may speed up this process. Demand for this type of housing will be influenced by new forms of urban transportation. For people remaining in suburban areas, four-day work-weeks and staggered working hours should ease the burden of rush-hour traffic. Again the historical relationship between metropolitan structure and metropolitan transportation will have been made clear.

Personal rapid transit systems—sometimes called "people movers" carry small groups of passengers quickly to their destinations.

Photo, Ste Bertin





AVIATION

Many hundreds of years ago the storytellers of the East could keep their listeners spellbound with tales of a wonderful magic carpet that carried the princes of Bagdad through the air. Today, without benefit of magic, people have conquered the skies.

THE HISTORY OF FLIGHT

Certain aircraft remain aloft because they are lighter than air. Others are heavier than air, but are driven by power plants or are carried up by powerful air currents. We shall begin our story with lighter-than-air craft—balloons and dirigibles—because in them people first began to fly.

LIGHTER-THAN-AIR FLIGHT

The principle of lighter-than-air flight is simple enough. If any object is lighter in weight than the volume of air that it displaces, it will rise upward in the atmosphere. The problem is to find a substance that is lighter than air.

The Chinese solved the problem many centuries ago. They learned that heated air weighs less than ordinary air. By inflating hollow paper dragons with hot air, they were able to send the toys aloft. No one made use of this idea for human flight until the eighteenth century. Joseph-Michel and Jacques-Etienne Montgolfier were two brothers who lived in France. They inflated paper balloons with hot air produced by straw fires and watched them rise in the air. Later they used globes made of silk and suspended cages from them. In these craft they sent chickens, ducks, and sheep aloft. Finally, on November 21, 1783, two young Frenchmen, Pilâtre de Rozier and the Marquis d'Arlandes, rose in a Montgolfier balloon and made a free flight of 25 minutes over Paris. They were the first humans to fly.

The practice of inflating balloons with hot air was soon abandoned. People came to realize that the recently discovered gas hydrogen is much lighter than air. In 1783 a French physicist, J.- A.- C. Charles, filled a silk balloon with hydrogen and sent it aloft without passengers. Somewhat later he made several flights himself in a hydrogen-filled craft. More balloon flights followed.

Boeing Co.

Modern aviation's complex technology—Boeing 767 twin-jet, wide-body commercial airplane fitted with a two-crewmember flight deck.

Soon the big gas bags were being flown in many lands. They were all "free balloons"—they could not be steered but flew wherever the winds carried them.

In 1897 the Swedish engineer Salomon August Andrée launched upon perhaps the most daring lighter-than-air flight ever attempted. With two companions he took off in a balloon from Spitsbergen in an attempt to float across the North Pole. For years there was no further word of the three adventurers. At last, in 1930, the bodies of the explorers were found on White Island, together with much of their equipment, including some undeveloped negatives of photographs taken by Andrée. The three unfortunates had been forced down on an ice floe and had managed to make their way to White Island, where they had perished of exposure and cold.

THE COMING OF DIRIGIBLES

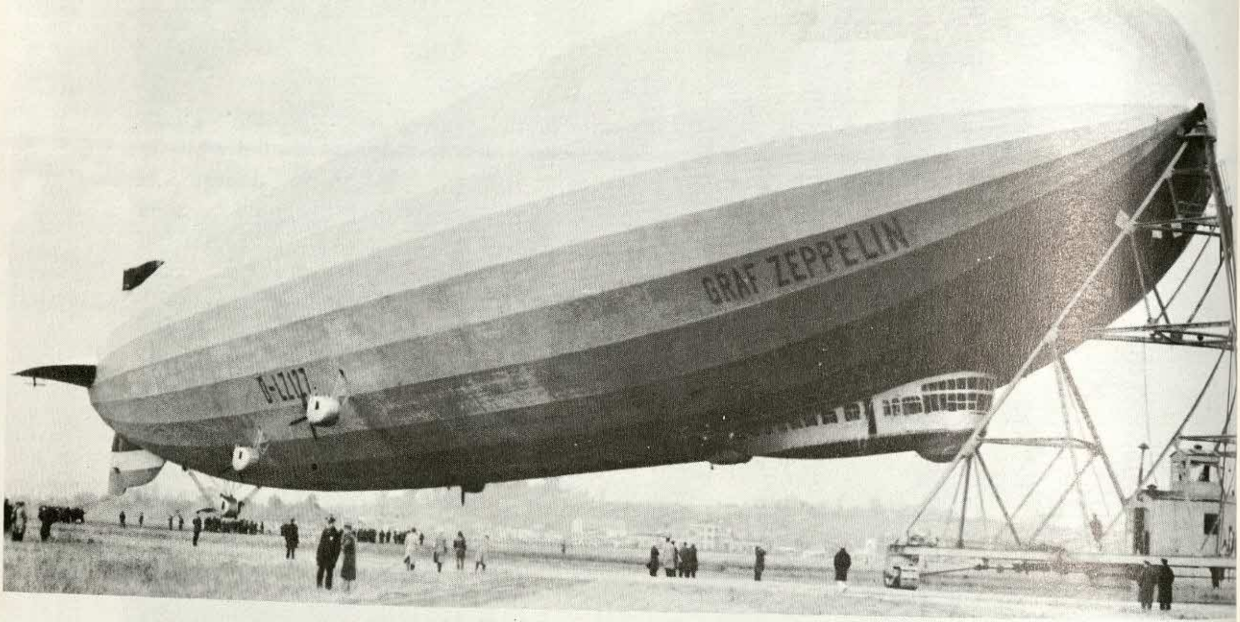
The disastrous result of the Andrée expedition clearly showed the haphazard nature of flying in a free balloon. From the earliest days of lighter-than-air flight, men had sought to develop a dirigible—a balloon that could be fully controlled while in the air. Some of the early students of aeronautics thought that this could be done by means of sails, oars, and rudders, but such devices as these proved futile.

In 1851, a Frenchman, Henri Giffard, fitted a big balloon with a steam engine that drove a propeller. Giffard's dirigible really flew, attaining a height of 1,520 meters. It answered its controls quite well, but it was altogether too slow. On a windless day its top speed was only slightly above walking speed. The fact was that the engine was much too heavy, considering the slight amount of power it produced.

It was not until lightweight gasoline engines were developed that really successful dirigibles were constructed. Alberto Santos-Dumont, a wealthy Brazilian living in Paris, built 14 dirigibles, powered by gasoline engines, between the years 1898 and 1908. With one of these airships he won a prize of $20,000 for rising in the air at a place a few kilometers away from the Eiffel Tower, circling the tower, and then returning to the starting point, all within half an hour. Santos-Dumont's dirigibles were quite primitive. They consisted of sausage-shaped balloons under which light keels, carrying the engines and crew, were slung.

In the meantime, Count Ferdinand von Zeppelin, a retired German army officer, had started to build rigid dirigibles. He constructed a framework of aluminum for his airships and divided the interior of the craft into compartments, which were filled with small gas bags called ballonets (little balloons). Two cars, one for the engines and the other for the crew, were suspended from the framework. The Count's dirigibles, called "zeppelins" after their inventor, proved to be quite successful. In the years before World War I, thousands of passengers were carried in them.

Free balloons and dirigibles saw service in World War I (1914-1918). Nonrigid dirigibles were used for antisubmarine patrol in coastal waters. The English had given the name of "limp airships" to all such craft. The particular model used for coastal patrol in World War I was known as



Goodyear Aircraft

The *Graf Zeppelin*, 237 meters long and 110,500 cubic meters in volume, was the most successful of the giant dirigibles. It flew from 1928 to 1939.

Type B-limp. This gave rise to the word "blimp," which is still used for a nonrigid dirigible.

After the war, the most important use of free balloons was in scientific research. The stratosphere—the upper air—was explored by small, crewless, hydrogen-filled balloons. Each of these contained a radiosonde—a collection of miniature scientific instruments. These automatically operated a tiny radio transmitter, which continuously sent reports to ground stations. When the atmospheric pressure at great heights became too low, the internal pressure of the hydrogen gas within the balloon caused it to break. The radiosonde then descended to earth by parachute. Radiosonde-carrying balloons are still widely used by weathermen in different parts of the world.

On May 27, 1931, a Swiss physicist, Auguste Piccard, and an assistant made an epoch-making flight to the stratosphere, using a free balloon, from which a big metal ball was suspended. The balloon was only partially filled on the ground in order to allow for the expansion of the gas as it rose. Piccard and his assistant took their places in the metal ball, which was equipped with a great deal of special apparatus. The balloon rose majestically to a height of 15,781 meters. The occupants brought back with them much valuable information about solar radiations and cosmic rays. Other flights to the stratosphere followed.

THEIR LATER CAREER

Rigid airships seemed destined to play an important part in aviation after World War I. A few of these craft had impressive records. In 1929 the German commercial airship *Graf Zeppelin* flew around the world in a little over 21 days. Later it was used in regular passenger service between Germany and South America. It crossed the Atlantic more than 125 times, carrying 13,000 passengers in all.

On the whole, however, misfortune seemed to dog the big gas bags. There was a series of terrible disasters. One after another of these giants of the air caught fire in mid-air, or crashed to the ground, or fell into the sea. The last of these disasters happened in 1937, when the German ship *Hindenburg* burst into flame as she was nosing up to her mooring mast at Lakehurst, New Jersey, after a flight from Germany. She was destroyed, with a loss of 36 lives.

The rigid airship was not the only type of dirigible used in this period. The semirigid type, supplied with a keel and a few ribs, also saw a certain amount of service. Nonrigids saw considerable service.

Another development was the use of helium to inflate lighter-than-air craft. For years, all free balloons and airships had been inflated with hydrogen or with illuminating gas, which contains a large proportion of hydrogen. Hydrogen is the lightest of all gases, but it catches fire easily. Therefore it is very dangerous. Helium is much more satisfactory for lighter-than-air craft. Though it is heavier than hydrogen, it is much lighter than air and cannot catch fire. This gas is found in the sun, in the atmosphere in very small quantities, and in natural gas derived from wells in Texas. In the 1920s a method was developed for extracting helium at reasonable cost from these Texas wells. From that time, U.S. airships were inflated with helium instead of hydrogen.

Lighter-than-air craft are not in much use today, but they have not disappeared from the skies. Free balloons are still used for manned flights, but generally only in sporting competitions. Blimps are seen occasionally. As for unmanned balloons, they are used quite widely at the present time for scientific purposes. They are sent aloft regularly by weathermen to determine wind speed and direction. They also play a part in upper-air and space research.

The *Hindenburg* disaster at Lakehurst, New Jersey, on May 6, 1937, killed 36 people. Apparently, atmospheric electricity ignited a hydrogen leak.

U.S. Air Force

HEAVIER-THAN-AIR FLIGHT

Some of the earlist pioneers in heavier-than-air flight tried to imitate the flight of birds. In the thirteenth century an English monk, Roger Bacon, proposed that men should use flapping wings, like those of birds, to achieve flight. Several centuries later the great Italian artist-scientist, Leonardo da Vinci, drew up plans for an ornithopter, or bird machine, following the suggestion of Bacon. The flapping wings of the craft were to be operated by hand. Leonardo never developed a successful ornithopter, however.

A nineteenth century English scientist and inventor, Sir George Cayley, tried a different approach, and as a result became the father of heavier-than-air flight. He had noticed that birds could remain aloft for long periods of time without moving their wings. He proceeded to fashion a number of gliders with wings shaped like those of birds. Men running against the wind launched the craft, which made a number of short flights. Cayley never succeeded in building a man-carrying glider. The first to do so was a Frenchman, Jean-Marie Le Bris, who made a short flight in 1855 in a glider that was built on the model of the wing structure of the graceful albatross.

Later in the century, other enterprising pioneers experimented with gliders. Foremost among them was Otto Lilienthal, a German inventor. First he made a thoroughgoing study of the theory of heavier-than-air flight. Then in 1891 he constructed a curious kind of glider that outdid all its predecessors. It combined batlike wings with a strap arrangement that permitted Lilienthal to hang from the center of the machine while it was in flight. He controlled it by swinging his legs and his trunk this way and that. Lilienthal was flying one of his "hang gliders" in 1896 when he lost his balance, crashed to the ground, and was killed.

His work was carried on by Percy S. Pilcher in England and Octave Chanute in the United States. Many improvements were made in the glider. Chanute devel-

Musée de l'Air, Paris

Otto Lilienthal, a German engineer, flew his batwing glider many times in the 1890s, controlling his flight to some degree by swinging his legs.

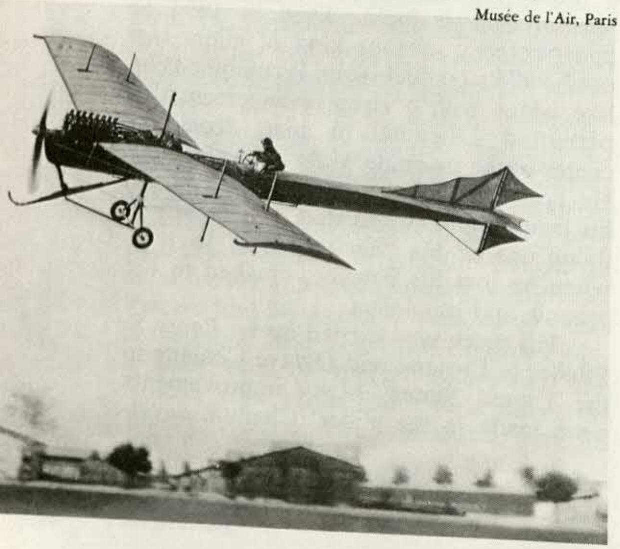
oped a machine with wings that could be twisted while in flight. He added a vertical tail that stabilized the glider and kept it flying in a straight line.

THE WRIGHT BROTHERS

Orville and Wilbur Wright, two bicycle builders of Dayton, Ohio, began experimenting with gliders at the turn of the century. They discarded many of the ideas of their predecessors. For one thing, the trailing or rear edges of the wings were made flexible and were worked by ropes in order to control the lateral, or side-to-side, position. The gliders of the Wright brothers proved to be very successful. In one of them they made more than a thousand flights during September and October 1902.

Aviators were busy designing experimental planes in the early twentieth century. Below, Hubert Latham of Great Britain flies his monoplane *Antoinette*.

Musée de l'Air, Paris



The brothers now felt that the time was ripe for powered heavier-than-air flight. The idea was by no means new. In 1842 William S. Henson of England had constructed a full-scale monoplane, which was to be driven by a steam engine. It was a total failure. His partner, John Stringfellow, built a small-scale-model steam-driven plane, which he managed to get aloft in 1848. However, these early experiments could go no further, because the steam engines of those days were much too heavy to be used in planes.

When the Wrights began to work on a powered airplane, the gasoline engine had already been developed. But the brothers found that no existing motor was light enough for their flimsy craft and at the same time powerful enough to propel it through the air. They decided, therefore, to develop an engine of their own.

On December 17, 1903, the Wrights were ready for their own attempt at powered flight. It took place on the beach near Kitty Hawk, North Carolina. A single rail was laid upon an incline at the beach. A truck was put in place upon the rail at the top of the incline. Then the plane, which was provided with skids, was balanced on the truck. Orville Wright got into the machine and lay prone on the lower wing. The motor was started and warmed up while assistants held the plane in position. The signal was given, and the craft was released. The truck slid down the rail. The plane rose into the air, leaving the truck behind. It flew for a distance of 36.6 meters, remaining aloft for 12 seconds, and then landed on its skids.

The plane in which the Wrights had achieved flight was a biplane (two-winged plane). Its wings were made of fabric and were held together by struts and wires. The engine was set on the lower wing, to the right of the pilot. The propellers were at the back of the plane and pushed it along.

THE AGE OF FLIGHT BEGINS

It was not until the Wright brothers had made a number of flights in England that the public at large began to show genuine interest in heavier-than-air flying machines. Other pioneers developed planes of their own. Some of these were biplanes. Others were triplanes, with three wings. Still others were monoplanes, with but a single wing. One of the most successful of these early flying machines was a monoplane built by Louis Blériot, a Frenchman. In this frail craft he crossed the English channel in 1909 in 37 minutes—a remarkable feat for that time.

When World War I broke out in 1914, airplanes were still a novelty. A few military services had employed tham for scouting purposes. They had carried mail in the United States and in England, but no regular mail service had been established.

The airplane really came of age in the course of the war. Shortly after the end of the war, two great flights showed how much had been accomplished. In May 1919, the United States flying boat NC-4 flew from New York to Plymouth, England, by way of the Azores and Lisbon, Portugal. A month later, two Englishmen, Captain John Alcock and Lieutenant Arthur Brown, made the first nonstop flight across the Atlantic, flying from Newfoundland to Ireland.

Governments sold their surplus war planes at low prices. Many former war pilots bought these planes. They used them for "barnstorming" and also to take passengers on short flights. Air-transportation companies scheduled passenger flights. Regular airmail service was established. Airplane engines were improved. Metal and other materials began to replace the wood and fabric of the older planes.

On May 20, 1927, Charles Augustus Lindbergh, a young U.S. aviator, took off from Roosevelt Field, near New York City. After 33 hours and 30 minutes of a thrill-packed flight through fog and sleet over the Atlantic, he landed at Le Bourget Airport, near Paris, France—the first nonstop solo flight between the two cities.

Musée de l'Air, Paris

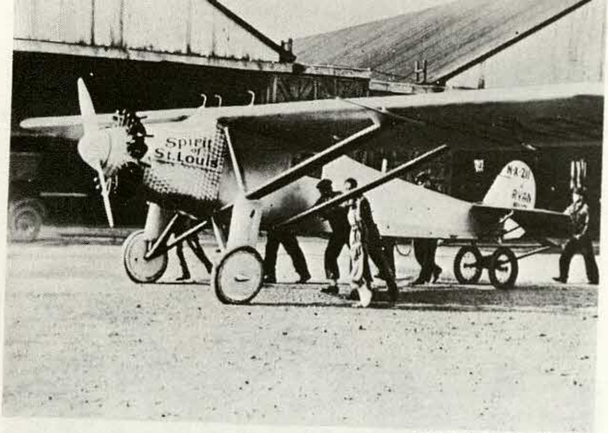
After their first successful flight in 1903, the Wright brothers demonstrated their plane at many locations—as here, near Pau, France, in 1908.

The airplane industry continued to forge ahead in the 1930s and 1940s. The airplane became a major factor in the world's transportation systems. Freight planes opened up to commercial enterprise new areas in the Far East, in Canada, in South America. The military services of the world built up powerful air fleets over this period of time.

THE JET PLANE ARRIVES

Jet planes made their appearance toward the end of World War II. These were propellerless craft, which derived their motive force from gases expelled from the rear of the plane. After the war, jet planes were greatly improved. Their flight range and speed were increased and they were made more maneuverable. Jet transport planes were developed. Work was sped on giant rockets that were sent hurtling into the upper air and finally into outer space and to other planets. Unmanned artificial satellites and manned capsules were sent up by rockets.

Today vast numbers of air transports, air freighters, and private planes make their way through the skies. For a discussion of other advances in aviation, see the articles "Jet Propulsion" and "Supersonic Flight" in *The New Book of Popular Science.*



U.S. Information Service

The Spirit of St. Louis is wheeled into place at an airport. Charles Lindbergh won world fame in this plane in 1927 when he crossed the Atlantic.

SPECIAL TYPES OF PLANES

The typical plane is land-based and uses a runway for takeoff and landing. It has comparatively large wings and a tail assembly. It is powered either by gasoline engines connected to propellers or by jet engines. Not all planes, by any means, are like this "typical" plane we have just described. There are a number of special types, which we shall briefly consider here.

SEAGOING PLANES

There are several types of seagoing planes. In the *seaplane,* landing wheels are replaced by floats, which support the craft in the water when it is attached to its moorings, or when it moves slowly. When it proceeds at greater speed through the water, water is deflected from the upper surfaces of the floats, and lift is provided. The floats cannot be retracted into the fuselage of the plane, and they produce a certain amount of drag. The *hydro-ski aircraft* uses skis, which can be retracted, instead of floats. The *flying boat* has wing-tip floats. The hull itself, however, is provided with neither floats nor skis, but itself floats in the water. The *amphibian* is a versatile plane, with a flying-boat hull and landing gear. It can take off and land on either land or water.

GLIDERS

Gliders still maintain a place, though a modest one, in aviation. The glider has much the same arrangement of wings, tail, body, and controls as the conventional propellered plane. However, the motor and the propeller and the equipment that goes with them are missing. Gliders are generally launched by automobiles or powered planes. Sometimes they are catapulted upward into the air.

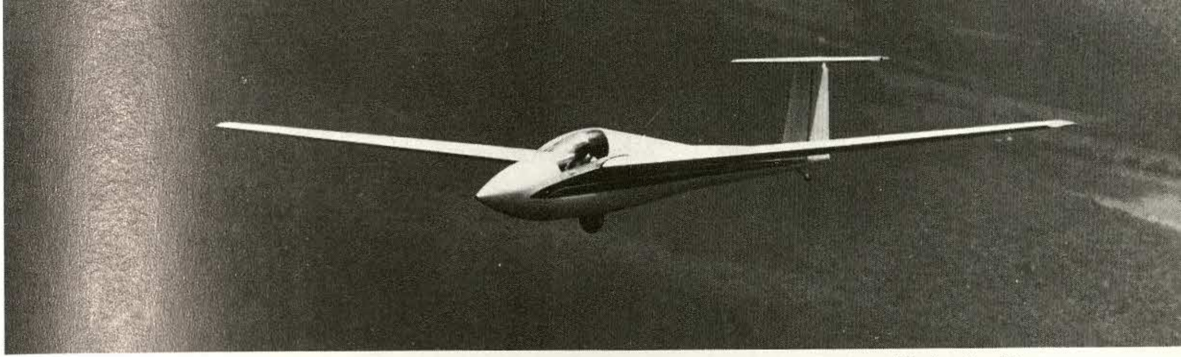
Undoubtedly, the most spectacular kind of glider is the sailplane, or soaring glider. It is so light and has such low drag that it can ride thermals, or ascending currents of air. By taking advantage of such currents, skillful sailplane pilots can perform almost incredible feats. Sailplanes have soared to over 14,000 meters in altitude and have covered distances of more than 900 kilometers.

HELICOPTERS

The helicopter is driven by propeller-like rotary wings that whirl above the fuselage. The first successful rotary-wing plane was the Autogiro, invented by the Spaniard Juan de la Cierva and first flown successfully in the summer of 1923. This craft was provided with an ordinary propeller as well as with a rotor. At the takeoff, the rotary wings were rotated by means of a special connection with the engine. Once the autogiro was in flight, the rotor was disconnected from the engine. The blades continued to turn, however, because of the air moving past them. The autogiro had no wings. The pilot controlled it in flight by the use of standard tail surfaces and by tipping the rotor.

The autogiro has been supplanted by the helicopter, which has done away entirely with the propeller and tail assembly. Many pioneers in the field of aeronautics worked to develop this revolutionary type of plane. Foremost among them were the German Heinrich Focke, the Frenchman Louis-Charles Bréguet, and the Russian-born American Igor I. Sikorsky.

The rotary blades of the helicopter are turned continuously by the engine. The rotor is not connected to the motor when the engine is being warmed. For the takeoff, the pilot throws in a clutch, engaging a gear. The rotor then begins to turn.



Schweitzer Aircraft Corp.

The modern sailplane is capable of extended flight, soaring to very high altitudes and covering hundreds of kilometers.

The helicopter is controlled by changing the pitch of the blades. In what is called cyclic pitch, the angle of individual blades is changed. If the pitch of a blade on one side is increased while the pitch of the opposite blade is decreased, the machine will fly in the direction of the first blade. In collective pitch, the angle of all the blades is changed in the same way at the same time. If the pitch is increased, the helicopter will rise; if decreased, it will descend.

A problem that all helicopters face is the tendency of the fuselage of the craft to rotate in the direction opposite to that of the rotor blades. This tendency is called "torque." The most common method of correcting torque is to mount a small engine-driven rotor, turning on a horizontal axis, on the tail. This rotor—the contrarotating rotor—causes the fuselage to move in the direction opposite to that produced by torque. Some helicopters have more than one contrarotating rotor.

The helicopter is much slower than a propellered craft or jet craft of the same horsepower. Its great advantage lies in its maneuverability.

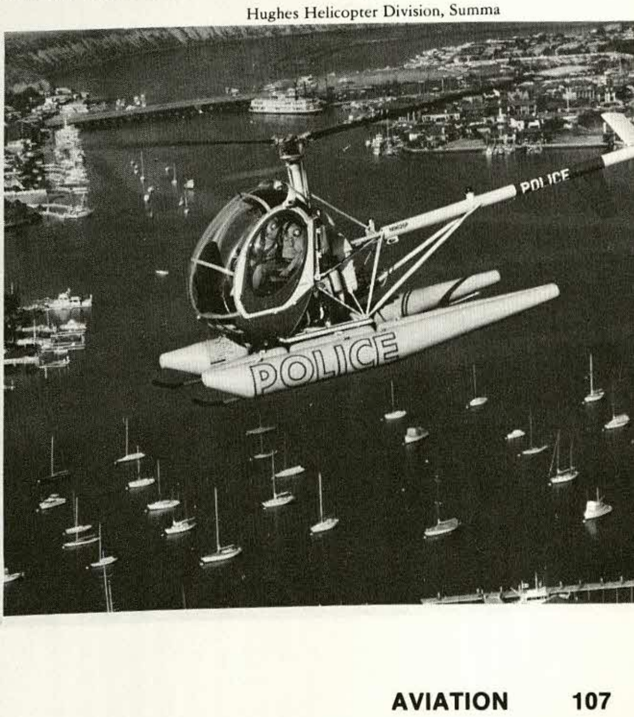
VTOL AIRCRAFT

The term VTOL stands for "vertical take-off and landing." It is generally applied to heavier-than-air craft which, like helicopters, can rise and land more or less vertically but which generally have speed and range comparable to those of a conventional aircraft. There are a number of VTOL designs.

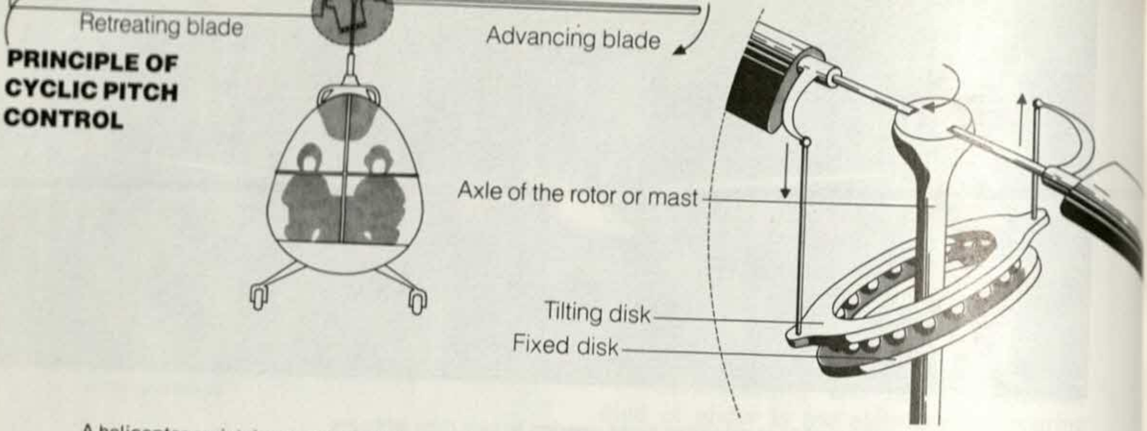
In the dual propulsion system, the aircraft has a rotor, like that of a helicopter, for taking off, hovering, and landing; it also has propellers for horizontal flight. In another system, there are no propellers. The rotors may be tilted so as to provide vertical thrust for take-off and horizontal thrust for horizontal flight.

In certain cases, rotors are discarded entirely. In the tilt-wing type, the fuselage and tail assembly remain horizontal at take-off or while landing. The propellers and wings, however, can be tilted. They move together in changing from take-off to horizontal flight and then to landing.

Hughes Helicopter Division, Summa



The versatile helicopter is a form of VTOL (Vertical Take-Off and Landing) aircraft. It finds frequent use in large cities for the monitoring of traffic and as an aid in police surveillance.



PRINCIPLE OF CYCLIC PITCH CONTROL

A helicopter maintains steady flight by continuously changing the angle at which its rotor blades meet the air. Left, the advancing blade is set at a small angle of attack, while the receding blade is at a larger one. The drawing at right shows in detail the mechanism by which this is achieved.

The ducted-fan airplane employs so-called fan ducts. A fan duct is a fan, or propeller, surrounded by a ring, or band. The two fan ducts, one at the tip of each wing, can be tilted so that the fans rotate on a vertical axis. This provides vertical flight. For horizontal flight, the ducts are tilted so that the fans turn on a horizontal axis. In another model, known as the flying jeep, the two ducted fans are not movable but are mounted rigidly, so as to turn on a vertical axis. The craft is tilted slightly to provide forward flight. The flying platform is a simplified version of the flying jeep. There is but one duct. The pilot stands on a platform mounted atop the duct and grasps a semicircular railing.

The principle of thrust deflection is applied in some models. In propellered planes, large wing flaps can be turned downward. The slipstream for the two propellers, set at the leading edges of the wings, is bent downward, thus providing vertical thrust. In the case of jet craft, the gases streaming from the jet nozzle are deflected downward to give vertical thrust. In some jets, the entire engine is tilted to provide vertical thrust at take-off.

Enrico Natali/Rapho/PR

The lifting force, in some of the models described above, is not sufficient to provide vertical takeoff; yet it is strong enough to get the planes in the air very quickly. Such planes are known as STOL aircraft, the STOL standing for "short takeoff and landing."

FLYING AN AIRLINER

Let us board a big airliner as it prepares to take off on a regularly scheduled flight from one airport to another. The big ship has already been checked by mechanics. It has taken on gas and oil. Full information has been obtained about weather conditions along the proposed route. The pilot has filed a flight plan with the airport authorities. This plan includes the direction and altitude of flight.

The pilot now makes contact by radio with the control tower of the airport and gets the exact time, the speed and direction of the wind, and special instructions concerning traffic at the airport. The pilot is told what taxi strip to use in taxiing over to the takeoff position. At last the signal is given, and the big plane rises from the ground. When it is well under way it retracts its landing gear. It remains in radio contact with the control tower for some time. Then another control station along the route takes over.

HIGHWAYS IN THE SKY

The plane is now headed for its destination. The airway is almost as well defined as the highways along which automobiles make their way. It has a definite height and width, and the pilot has to stay in it. Airplanes must obey traffic rules while in the sky. These rules vary from one country to another.

The navigator follows the course of the plane on maps or charts. The pilot keeps the ship on the course in any sort of weather by following the signals sent out by radio transmitters of an omnirange system or, in the largest aircraft, by presetting the course into a sophisticated computer-controlled autopilot.

The high-frequency omnirange system is appropriately named. The omnirange station transmits radio beams in all directions. The airplane receives the signals on a special receiver that enables the pilot to determine direction and distance with respect to the station sending the signals. Omnirange is equally useful for navigation on airways or off airways. Since it operates on very-high-frequency bands, the signal is virtually

Cessna Aircraft Company

Left, small commercial aircraft are used routinely to provide commuter service in many areas. Right, this single-engine airplane equipped for high-altitude and bad-weather flying typifies a trend toward heavier, more versatile business aircraft.

The Airbus A-300 is an airliner developed under the joint sponsorship of the French, German, Dutch, and Spanish governments. The airplane is powered by two turbofan engines, and it can accommodate up to 300 passengers in its wide fuselage.

free from any type of static interference. Thus, the pilot can receive omnirange signals at all times, even in the midst of a thunderstorm.

The most modern commercial airliners are directed by an inertial navigation system that depends on a gyroscope, speed detector, and computer (as well as backup computers) to determine the airplane's location at any time. It is more or less independent of all outside references. Using a small keyboard or programmed destination cards, the flight crew programs the system's computer with the latitude and longitude of the departure point and of each checkpoint in the flight plan. The plane's automatic pilot follows the plan, making all the corrections that are necessary. The crew is required to check coordinates at prescribed intervals, and may remove the aircraft from computer control at any time to avoid bad weather or to otherwise adjust for outside conditions.

LANDING THE PLANE

The pilot now approaches the airport. At night a revolving beacon sends its rays circling through the darkness. The pilot calls the airport's control tower by radio, reports the number and model of the plane, the airline to which it belongs, its position, altitude, and airspeed, and asks the air-traffic controllers for landing instructions.

If the air traffic at the airport is heavy, the pilot is told to circle in a designated area at a definite altitude and airspeed. Planes flying at different altitudes, waiting for a chance to land, are said to be "stacked." Newly arrived craft go to the top of the stack.

If visibility is good during the daytime, landing is a comparatively simple matter, once clearance has been given. At night, too, under favorable conditions, the pilot has little difficulty in bringing the plane to the ground. The edges of runways are illuminated by small lights sunk flush with the runway. Red warning lights or red patterns of light are used on all obstructions in the vicinity. A line of lights across the runway shows where it comes to an end.

Airbus Industrie

AIR-TRAFFIC CONTROL

A plane without radio equipment is not permitted to use a radio-controlled airport, except in an acute emergency. But even at smaller airports without radio facilities, pilots cannot take off and land at will. Operators may provide certain instructions to arriving or departing planes by means of green and red signal lights. These lights are flashed from a device called a "biscuit gun." It is held in the hand by means of a pistol grip and is operated by a trigger. At the takeoff a red light is a signal to halt. The green light gives clearance to the pilot. A red light warns incoming planes to continue circling the field. A green light means that the plane can land.

Sometimes the control tower reports to the incoming pilot that visibility is poor at the airport. If the plane is not equipped to make landings under such conditions, it proceeds to another airport.

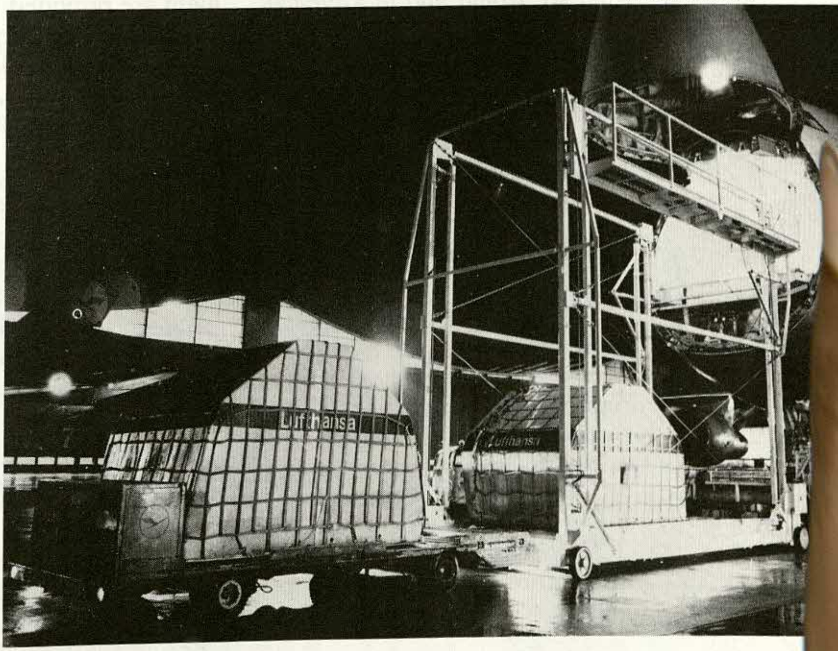
Nowadays many planes make landings safely when the landing field is invisible because of fog. If an airport is equipped with an Instrument Landing System (ILS), the pilot can bring a plane in without looking outside the cockpit. A transmitting station at the far end of the runway sends out a pair of horizontal beams, like those sent out by radio range. Both beams are on the same radio frequency and can be received in the aircraft by a single radio receiver. The pilot keeps the plane between the two beams, and is said to be on the localizer course. A second transmitter sends out another pair of beams, one above the other. The pilot keeps within the second set of beams, and is said to be "on the glide path." A series of "fan marker" transmitters, so called because each one sends a fan-shaped beam straight up in the air, mark the end of the landing field. A plane passing these and still squarely on the localizer course and glide path will land in about four seconds. Generally, however, pilots are required to seek an alternate airport if they cannot see the runway after arriving at a designated minimum descent altitude.

GROUND CONTROL APPROACH

Another very effective type of landing system is Ground Control Approach, or GCA. Two radar sets are operated at the landing area. The screen of one set shows a picture such as the operator would see from high in the air over the runway and looking down toward the ground. The picture shown on the other screen shows what the operator would see from on the ground, far off to one side of the runway and looking toward it. The operator can also see the incoming plane on both screens. The operator talks with the pilot of the plane by radio and tells the pilot how to shift course, if necessary, in order to keep headed for the runway and to remain in the proper glide path. The operator also informs the pilot how far the plane is from touchdown.

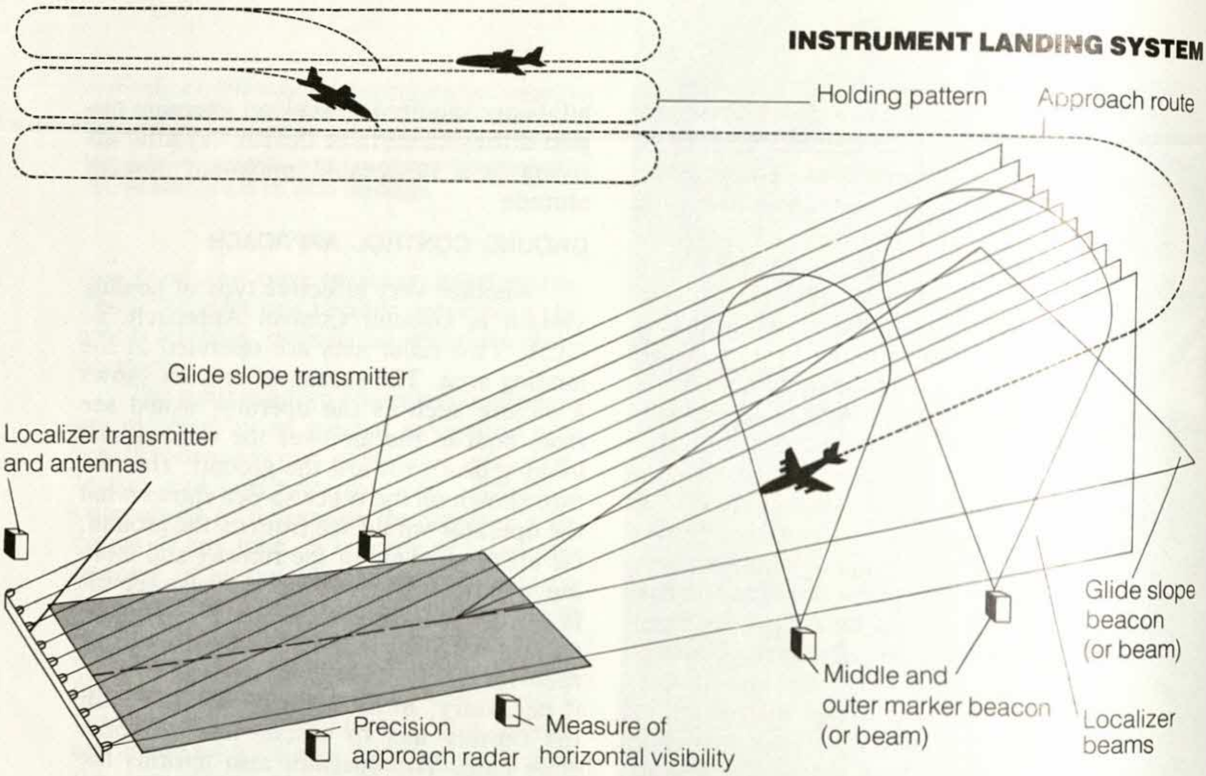
PARTS OF A TYPICAL AIRLINER

To have some idea of the amazing advances that have been made in the field of aviation since the Wright brothers first flew



Lufthansa Airlines

Airplanes are in much use as freighters all around the world, sometimes taking goods to airports that do not have equipment for loading or unloading. The loading device at right is carried aboard the plane, and can be assembled and disassembled quickly.


INSTRUMENT LANDING SYSTEM
Holding pattern
Approach route
Glide slope transmitter
Localizer transmitter and antennas
Glide slope beacon (or beam)
Middle and outer marker beacon (or beam)
Localizer beams
Precision approach radar
Measure of horizontal visibility

Radio and radar devices aid airplanes in landing at modern airports. Instruments on the plane electronically indicate the correct path of descent. Diagram at top shows the way in which the planes "stack" to await landing.

their "crate" of fabric and wood and wire, let us see what we would find in a typical airliner.

THE FUSELAGE

First of all, there is the fuselage, or body, which carries the weight of the crew, passengers, and cargo as well as the galley, the ventilating apparatus, and the radio equipment. The fuselage must also support the weight of the wings and, consequently, the weight of the structures supported by or suspended from the wings—the engines, fuel tanks, and landing gear. Some airplanes also carry fuel tanks in the fuselage.

The principle of construction of the fuselage is that of a hollow column or cylinder. In small planes the fuselage may be all in one piece. It is usually constructed of metal. In big planes it is generally made up of sheets of aluminum alloy, riveted into sections and reinforced by hoops of steel and by stiffeners, running parallel to the length.

Airliners destined for high-altitude flight are provided with pressurized cabins. In these the air pressure found at 2,400 meters is maintained, when the plane rises above that altitude, by means of an air compressor—the cabin supercharger. Pressurized cabins are of two kinds. In one type the cabin is an independent unit inside the fuselage. In the other type the walls of the fuselage serve as the outer walls of the supercharged cabin.

The windows in the fuselage are made of an acrylic plastic called Lucite or Plexiglas. Pilot windshields, or windscreens, as they are sometimes called, are of very heavy shatterproof glass in order to protect against birds crashing into them.

In one type of arrangement, the galley is behind the passenger quarters. The lavatory is aft of, or behind, the galley. Ahead of the passenger quarters are the baggage compartments. Baggage and cargo are also carried in the space below the passenger floor in some planes. The pilot and copilot sit near the nose of the plane, and the flight engineer, if one is required, sits behind them and to one side.

The wings are reinforced in much the same way as the fuselage. They usually carry the engines, the fuel tanks, and, often, the main landing gear.

POWER SYSTEMS

Hydraulic pressure is used to operate a number of devices on an airliner. Among other things, it serves to lower and raise the landing gear and to work the brakes. If the main hydraulic system fails, controls are generally worked by hydraulic power provided by auxiliary devices.

Every airliner has an elaborate electrical system. It is equipped with from two to four engine-driven generators and the same number of storage batteries. To save the batteries, the engines are started by an outside source of current, plugged into the airliner at the airport.

In the average big airliner, several hundred devices are electrically operated. Of course the radio equipment and the cabin, landing, and navigation lights use electric current. Electric motors run the fuel pumps, change the pitch of the propellers, and work the pumps that spray de-icer fluid on the windshield. Many of the engine and flight instruments that are found aboard an airplane are operated by electricity.

The fuel is stored in rubber self-sealing cells or in aluminum tanks. Each engine generally uses an independent oil system.

INSTRUMENTS

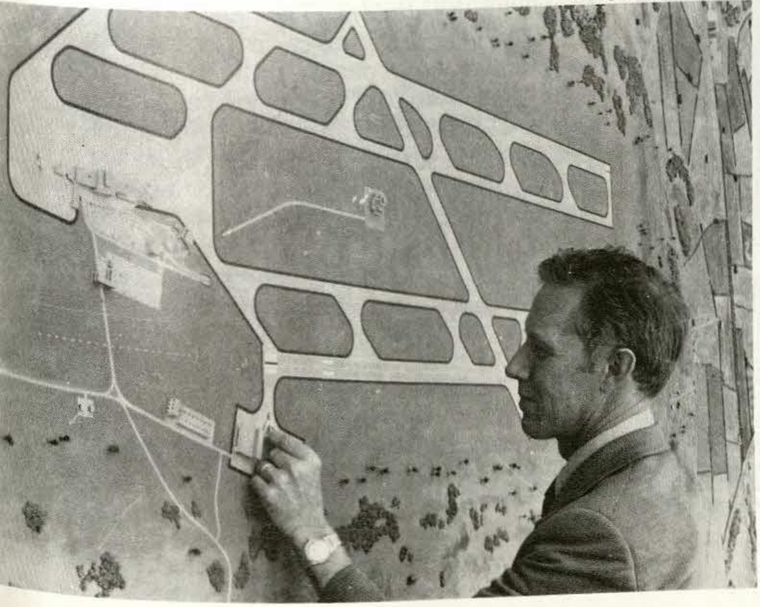
On every large airliner there are a great many instruments that provide information about the flight of the plane. They are grouped on the panel in front of the pilot and copilot.

The airspeed indicator shows the speed of the plane in flight. In the mechanical type, air is admitted to the pitot tube, a metal spike on the airplane wing. The more rapidly the plane moves, the more air rushes into the tube. The changes in air pressure cause a metal disk to move up and down. The disk movement affects the indicator of the airspeed dial on the instrument panel. The rate at which the plane is rising or descending is indicated by the rate-of-climb indicator, or variometer.

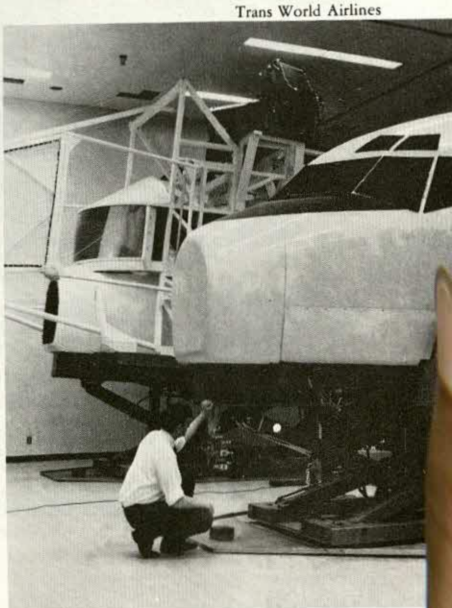
The altimeter is an aneroid barometer, which records the plane's altitude above sea level. Like all barometers, the altimeter

Training to be a pilot of a giant airliner is a long and exacting process. Many practice flights are made in simulators such as the one at the right, which carries all the instruments of a real cockpit. Scale models such as the one at left, of an airport, provide visuals for the simulated flights.

Georg Gerster/Rapho/PR



Trans World Airlines



© Dr. George Gerster/Rapho/PR

is affected by atmospheric pressure, which lessens as the altitude increases. Changes in pressure are registered on a dial.

The terrain-clearance altimeter indicates the distance of the plane from any obstruction on the earth's surface. This instrument sends a shortwave radio signal toward the ground. The signal is reflected back from the earth and is recorded. The time required for the round trip of the signal varies according to the distance of the plane from the surface of the earth. As in the case of the barometric altimeter, variations are registered in terms of distance limits. The instrument quickly tells when the pilot must climb higher in order to avoid a mountain peak or similar obstacle in the path of the plane.

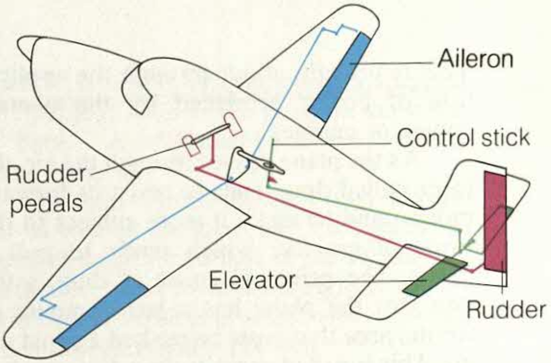
The bank-and-turn indicator shows the airplane's angle of bank. The gyro–artificial horizon shows the pilot the attitude of the plane in the air. It indicates whether the nose of the plane is low or high and also whether or not the plane is banking. Airliners are generally provided with an automatic pilot, operated by gyroscopes. Once the automatic pilot is set, it keeps the plane on its course.

Several kinds of compasses are used in an airliner. First of all, there is the conventional magnetic compass. The gyrocompass, or directional gyro, has a gyroscope instead of a magnet. If an airplane turns, the gyroscope remains in its former position, while the indicator line of the dial turns with the airplane. The radio compass has a needle that moves in response to radio waves sent out by radio-range stations. The Gyro Flux Gate compass picks up the electric currents that surround the earth. By means of an amplifier, it makes these currents strong enough to move a compass needle.

Most commercial aircraft and many private airplanes have weather radars. Some of these have navigational use.

After construction, these airplanes are readied for delivery to the various airline companies around the world that have purchased them.

BASIC MANEUVERS TO CONTROL AN AIRPLANE



A plane's flight is controlled by movable surfaces on wings and tail assembly, shown at top. Below: movement about the vertical axis, or yawing, is controlled by rudder on tail. Movement about the longitudinal axis, or rolling, is controlled by ailerons on wings. Movement about the lateral axis, or pitching, is controlled by tail elevators.

There are other flight instruments besides those that we have just mentioned. There are also a number of instruments that continuously record the performance of the engines. They indicate fuel and oil pressure, the temperature of the engine and exhaust gases, the rate of rotation, and the amount of fuel in the tanks.

WHAT MAKES A PLANE FLY?

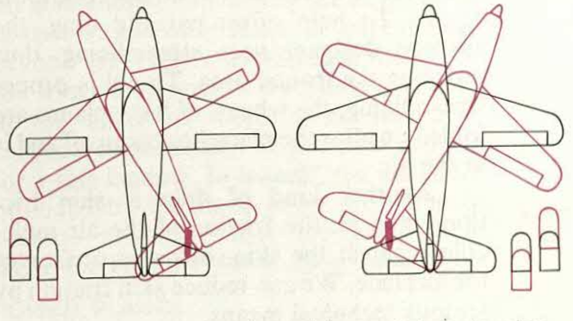
It seems quite wonderful for a big plane weighing many metric tons to make its way through what appears to be a void. Actually, the plane must make its way through the ocean of air just as truly as a steamer must make its way through the ocean of water.

A BALANCE OF FORCES

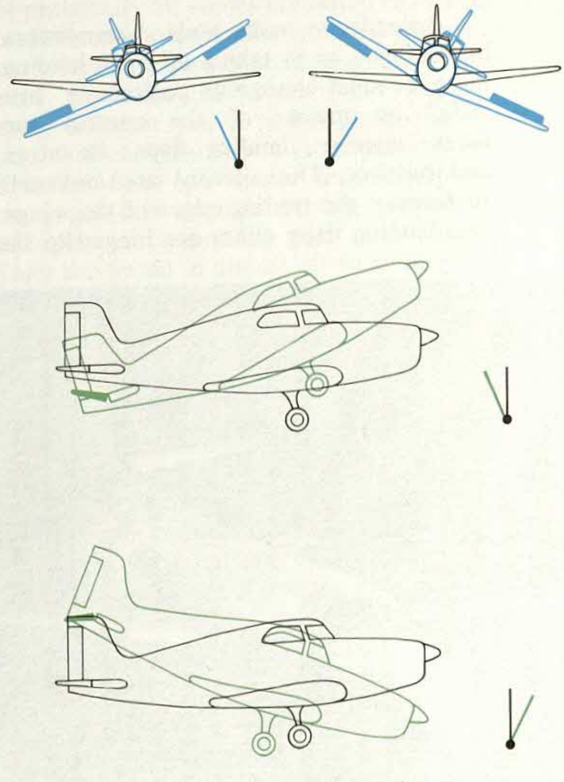
As the plane flies, the force of gravity is trying to pull it earthward. To offset this force, the plane uses an effective counterforce, called lift. This is brought about by the ingenious design of the wing. If you examine the cross section of an airplane wing, you will note that the upper surface is cambered, or curved, and that the leading, or front, edge is thicker than the trailing, or rear, edge.

When the wing is tilted at a certain angle, called the angle of attack, and moves rapidly, the air is deflected upward over the cambered upper surface of the wing. The speed of the airflow is increased and the pressure is decreased, in accordance with a law of physics called Bernoulli's Principle. At the same time, the wing pushes downward on the air beneath it, and the molecules of air, forming an elastic mass, push back. The pressure on the upper side of the wing is now less than the pressure on the bottom. The wing, therefore, is lifted up.

To produce lift in this way, the wing must be moving rapidly through the air.



Various ways of using the rudder pedals for turning



Various ways of using the control column

This is brought about through the application of power produced by the plane's engine or engines.

As the plane moves through the air, the force called drag tends to resist its forward motion and to make it more subject to the force of gravity, which tends to pull it down. The principal cause of drag is the fact that the plane has a large amount of frontal area that must be pushed against the air. This is called parasite drag, because it is produced by surfaces that do not contribute to lift. To help offset parasite drag, the airplane designer uses streamlining, thus reducing the frontal area. To aid in proper streamlining, the wheels of large planes are folded up after the plane has taken off and is in the air.

Another kind of drag is skin friction—that is, the friction of the air molecules against the skin, or outer surface of the airplane. We can reduce skin friction by various technical means.

Cessna Aircraft Co.

THE CONTROL SURFACES

In order to make a plane maneuverable in flight, or in taking off or in landing, the pilot must change its position or "attitude" by means of the control surfaces—ailerons, landing flaps, elevators, and rudders. The ailerons are moveable surfaces at the trailing edges of the wings. The landing flaps either are hinged to the fixed section of the wings or are so arranged that they can move rearward along a track. Both elevators and rudders form part of the tail assembly, which contains fixed and movable elements. The fixed elements of the assembly are the horizontal stabilizer and the vertical fin. The elevator is hinged to the rear of the stabilizer; the rudder, to the rear of the fin.

Manos—Magnum Photos

Some of today's small executive aircraft are also mounted with jet engines. This twin-turbofan plane can cruise at about 640 kilometers an hour, and it seats five passengers.

Hetier

Left: a small biplane turns upside down in the course of an acrobatic maneuver. Stunt flying is a popular feature of air shows. Above: because of their ability to land on water, these small planes provide regular air service to regions in Alaska that are otherwise hard to reach.

The pilot moves the rudder by means of pedals. In some small planes the pilot works elevator and ailerons by manipulating a joystick—a lever that rises directly in front of the pilot's seat. It was originally called the Joyce stick, after its inventor. In most planes today, the joystick is replaced by a steering column provided with a wheel. Hydraulic devices, electric motors, or various mechanical "boosters" help the pilot move the bulky control surfaces.

The elevators are the controls that cause the plane to climb and descend. When the pilot pulls the stick or the control column back, the hinged elevators swing upward. The airflow hits the raised elevators. It forces the tail down and the nose upward, and the airplane begins to climb. When the stick or control column is pushed forward, the hinged elevators swing down. The airflow hits the lowered surfaces, forces the tail up, and puts the plane in a descending attitude.

To change the longitudinal, or side-to-side, attitude of the airplane, the ailerons at the trailing-edge of the wing tips are used. The ailerons are worked by pushing the stick or turning the control wheel to the right or to the left. When this is done, the lift on one wing is increased, while that on the other is lessened. One wing, consequently, is raised, and the other is dropped. The plane is then in the position known as a "bank." A continued bank will make the plane turn.

To make a turn, the pilot uses the rudder as well as the ailerons. The rudder, as we have seen, forms part of the vertical tail surface. It turns toward the right when the right rudder pedal is pressed, and to the left when the left pedal is pressed.

The landing flaps are used for taking off and landing. When they are in the down or part-way-down position or are extended beyond the wing, they increase the lift on the wing. This permits the plane to remain in the air even when speed has been reduced considerably in order to provide for a safe landing. In takeoff, the added lift provided by the flaps helps the plane to become airborne. After the plane is in flight, the flaps are drawn up or pulled in.

POWER PLANTS

Until the mid-1950's, the power plants of practically all planes consisted of one or more internal-combustion gasoline engines, each driving a propeller. Today many aircraft, particularly large craft, have an entirely different type of power plant—the jet engine. (See the article "Jet Propulsion" in *The New Book of Popular Science.*) However, gasoline engines driving propellers still play an important part in aviation. They are found in almost all small aircraft and some larger planes.

The typical internal-combustion gasoline engine for airplanes operates because of the explosions of fuel in its cylinders. These explosions cause pistons to move back and forth within the cylinders. The reciprocal (to and fro) motion of the pistons is changed to rotary motion as it is transmitted through connecting rods to a crankshaft. The crankshaft, in turn, is hooked up to the propeller that drives the plane.

The number of engines in a plane ranges from one to six. Planes with as many as twelve engines have taken the air, but these have been experimental models. The engine of a light plane is set in the nose of the craft. Multiple motors are mounted on the wings or in pods on the fuselage.

Boeing International Corp.

Boeing International Corp.

The Boeing 747 is one of the giants of commercial aviation. It can seat nearly 400 people, while other models are used to carry freight. Left, an interior view of the plane while in flight, with a motion picture in progress.

Engines of more than 300 metric horsepower are generally provided with superchargers. The supercharger, operated by the engine, compresses the air that is drawn in from outside the plane and that is combined with gasoline vapor to form an explosive mixture. The supercharger provides more power for take-offs. It also makes engine performance more efficient at high altitudes by compressing the rarefied air that is found at heights high above the earth's surface.

The power generated in the gasoline engine, or engines, is applied through one or more propellers. Some planes are provided with pusher propellers. The propellers, directed toward the rear of the plane, push against the air, and the plane is driven ahead by this pushing effect. Generally, however, the propellers are of the "pull" type. Each propeller is really a screw. It cuts its way through the air much as a wood screw cuts through wood, and it pulls the plane along.

The blade of a propeller is an airfoil, with the cambered surface in front. The blades of low-powered planes are of laminated wood, while those of larger and more powerful planes are usually made of alloys of aluminum or magnesium.

The pitch of propeller blades—the angle at which they are set—has an important bearing upon flight. When we say that a plane has a low pitch, or a flat angle, we mean that it is approximately at right angles to the propeller shaft. In this position, it takes a more powerful "bite" of the air than in any other. The higher the pitch of the blade—the more it veers from the perpendicular position—the farther the blade can screw the plane forward with each revolution, but the less powerful its bite is. Hence a low pitch is preferable at take-offs, when most power is required. After the plane gains momentum in the air, it is not necessary for the bites to be so powerful, and so a higher pitch is preferable during ordinary flight through the air.

In some planes, the propeller can be full-feathered. That is, the pitch can be changed so that only the edges of the blades are turned toward the wind. This arrangement is particularly desirable when the plane is gliding with its motor shut off, since a propeller has least drag when it is full-feathered.

JET PROPULSION

by James J. Haggerty, Jr.

On August 27, 1939, the first flight of a jet-propelled airplane took place, and a new era in the history of aviation was ushered in. It has been an era of exciting progress. Planes powered by jet engines are not subject to the power limitations imposed on piston-driven planes. As a result, they have attained speeds and altitudes that even the most visionary scientist would hardly have predicted previously.

The principle of jet propulsion is quite simple. All jet-propelled craft are operated, wholly or in part, by jets of hot gases spurting from a tube—the jet nozzle—at the rear of the plane. The thrust of gases out of the jet nozzle produces an equal thrust against the front part of the engine. This is an example of Newton's third law of motion: that for every action, there is an equal and opposite reaction. It is this "equal and opposite reaction" that accounts for the recoil of a gun that has just been fired. In the case of the jet plane, as hot gases spurt out the jet nozzle, there is a "recoil"—a push against the front part of the engine. Since there is no thrust against the rear part of the engine, which is open to the outer air, the forward push propels the plane.

THE FIRST JET AIRCRAFT

Practical work on jet propulsion applied to aircraft started long before 1939. The first to explore the field was A. A. Griffith, whose name has been all but forgotten. Griffith, a scientist with the British Royal Aircraft Establishment, conceived the idea of employing a gas turbine engine to propel an airplane. The turbine was to drive a propeller. He conducted some preliminary tests in the late 1920s.

In the meantime a young flyer of the Royal Air Force, Frank Whittle, had also been studying the application of the gas turbine to aircraft propulsion. His ideas dif-

Almost all of the large airliners of the world today are powered by jet engines. This McDonnell Douglas DC-10, Series 30, has three turbofan engines, the turbofan being a form of turbojet in which fans provide added thrust.

McDonnell Aircraft Company

McDonnell Aircraft Company

Avions Marcel Dassault

Above, the McDonnell Douglas DC-9, Series 40, has two rear-mounted turbofan engines and cruises at about 900 kilometers an hour. It can seat a maximum of 125 passengers. Right, the Soviet Union's Tupolev-154 has three turbofan engines mounted at the rear, seats up to 167 people, and usually cruises at about 850 to 900 kilometers an hour.

fered from Griffith's in one very important respect: he proposed to eliminate the propeller. The plane would be driven entirely by the engine exhaust. The Air Ministry felt that Whittle's proposed engine had no military application. Therefore it refused to finance the construction of an experimental engine. For several years, Whittle was unable to go forward with his project. In 1935, however, he obtained financial backing and in the following year he founded Power Jets, Ltd., a company devoted to jet research.

Power Jets, Ltd., constructed a prototype engine that was bench-tested in the spring of 1937. By current standards it was not much of an engine, and it fell considerably short of Whittle's expectations, but it proved that jet propulsion could work. The company built a second and then a third engine. By the middle of 1939 the Air Ministry had changed its mind concerning jet propulsion. It decided to sponsor the construction of an engine designed for actual flight. At the same time it contracted for a new airplane in which the revolutionary engine could be used. The Gloster Aircraft Company received the contract for the construction of an airframe, which was to be powered by the first Whittle engine designed expressly for flight—the W-1. In May 1941, the airframe-engine combination was successfully flown for the first time. The engine provided a meager 385 kilograms of thrust—the term used in the measurement of jet power.

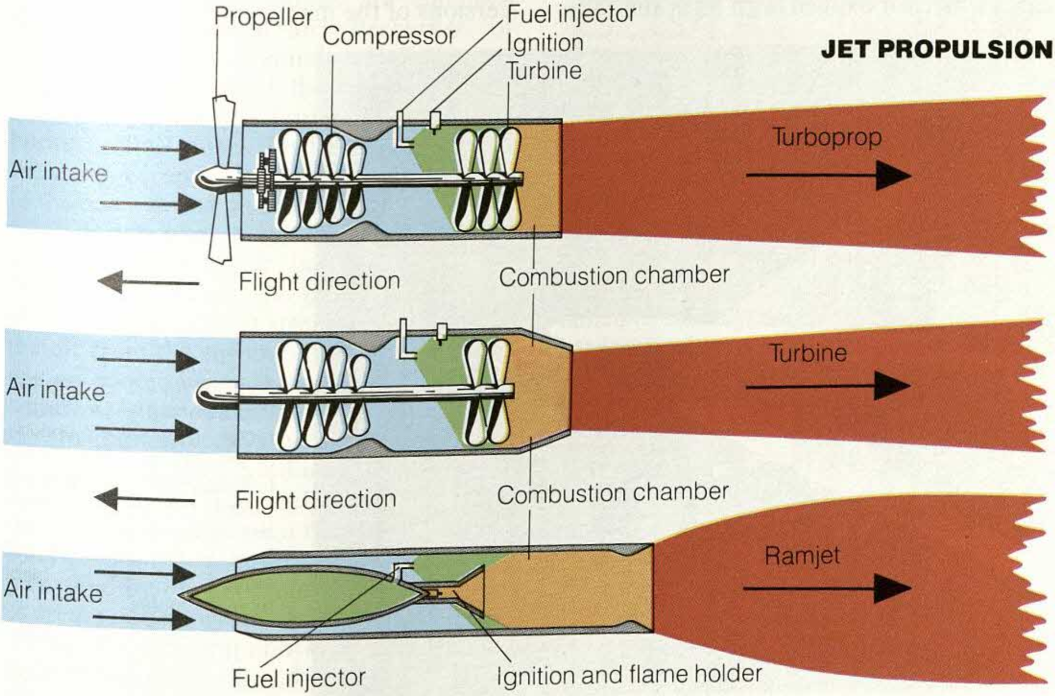
Although Whittle is commonly held to be the father of jet propulsion, his jet engine was not the first to power an airplane in flight. In Germany, Hans von Ohain had been working on the jet principle since 1935, independently of Whittle and apparently unaware of Whittle's research. By 1937 von Ohain had successfully bench-tested a small jet engine. On August 27, 1939, von Ohain's Heinkel 178, powered by a jet engine called the Heinkel S3B, made the first successful jet-powered flight in the history of aviation. The engine developed slightly more than 450 kilograms of thrust. In Italy, a Caproni-Campini plane made a jet-propelled flight on August 27, 1940.

Jet-propelled planes played no part in the early years of World War II. Later the Germans developed a pilotless jet plane, known as the V-1, or "flying bomb" or "buzz bomb," which was launched from sites on the western European coast. The first one was fired on June 12, 1944. The V-1 flew until its fuel was exhausted. Then it dived to earth and exploded. The Germans also built a huge rocket, called the V-2, which was first fired on September 8, 1944. It crashed into target areas in England at a speed much greater than that of sound.

Piloted jet planes appeared toward the end of the war. The British introduced the combat plane known as the Gloster Meteor I. It was powered by the Rolls Royce Welland engine, based on the original Whittle design. The Germans countered with the Messerschmidt 262, a jet fighter with a Junkers 004 engine. Neither the Gloster Meteor I nor the Messerschmidt 262 had much of a war record.

In the United States, jet-propulsion progress had lagged from lack of official interest, although some American engineers experimented with the principle in the late 1930s. In the early 1940s both the General Electric Company and the Westinghouse Electric Corporation began to work on

Diagrams show the basic construction of three kinds of jet power plant. Top to bottom: the turboprop, turbojet, and ramjet. Rocket engine is not shown.



JET PROPULSION

jet-propulsion engines. In October 1942, the Bell XP-59, with a GE I-16 engine, took to the air. June 1944 marked the highly successful debut of the lockheed XP-80, which was powered by a GE turbojet known as the I-40 and later as the J-33. The P-80 became America's first operational fighter.

Jet propulsion made tremendous progress in the years immediately following the end of World War II, as engine efficiency increased. Today engines of 4,500 kilograms of thrust or even more are common.

THE FOUR BASIC TYPES

There are four basic engine types that use the jet-propulsion principle: the rocket, the turbojet, the turboprop, and the ramjet. There are also several variations and combinations of these types.

Rockets. A rocket engine is really only a combustion chamber in which fuel, either solid or liquid, is burned. The resulting gases expand enormously under intense heat and are forced out from the rear of the rocket tube at high velocity, creating thrust. Unlike other types of jet engines, the rocket does not draw air from the atmosphere. It carries its own oxygen with it, in the form of liquid oxygen or of a compound such as hydrogen peroxide.

The great disadvantage of rocket power is the extremely high rate of fuel consumption. Most rocket engines can fly for only a few minutes. The chief advantage of the rocket lies in its ability to generate very high thrust in a comparatively small package. Rockets called jato units have been attached to jet planes or propellered planes to provide extra power for take-offs. The word "jato" comes from "jet-assisted take-off." Planes powered exclusively by rockets are still in the experimental stage. Because the rocket does not require air, it can be used in spaceships.

The United States actively engaged in developing rocket planes. The first one, the MX-324, took to the air in 1944. In 1947 the SX-1, or X-1, became the first aircraft to exceed the velocity of sound—about 1,060 kilometers per hour at high altitudes. It was powered with four alcohol and liquid-oxygen rockets, developing a total thrust of 2,700 kilograms. A number of other rocket planes were designed thereafter to solve different research problems. Generally, they were somewhat modified versions of the machines mentioned above.

The Boeing Company

The Boeing 747SP (Special Performance) is a longer-range, lower-weight version of the 747. It has a shorter fuselage than the standard model. The maximum seating capacity is about 300 people. The plane is designed for use on less-traveled routes.

The X-15 was a particularly powerful rocket vehicle. Equipped with a rocket engine fueled with liquid oxygen and ammonia and developing a thrust of 22,700 kilograms, the X-15 could fly at more than 5,800 kilometers an hour 160 kilometers above the earth. Considered the first manned spaceship, it answered many questions about travel in the uppermost reaches of our atmosphere.

Turbojets. Perhaps the best-known jet-type engine is the turbojet, or turbine-jet. In this form of propulsion, air is drawn from the atmosphere through intakes, usually located in either the nose or the wing roots of the plane. The air is compressed, led into a combustion chamber, mixed with injected fuel, and ignited. The resulting gases are forced rearward at high velocity. They drive a turbine connected to the main engine shaft on which the compressor is mounted. Then they escape through the nozzle. The reaction from the spurt of gases provides thrust. The escaping gases therefore not only propel the plane but also serve to compress the air drawn in through the intakes.

Some turbojet engines are equipped with a device called an *afterburner,* or reheat tube. This is simply a tail pipe attached to the rear of the engine proper. Fuel is injected and burned in the afterburner. This causes further expansion of the gases escaping from the engine, adding to the basic thrust and increasing the velocity. Another way of increasing thrust is to place a large cold-air fan in front of or behind the turbine. The fan forces masses of air into the exhaust stream, in addition to the air from the turbine itself. This kind of engine is known as a *turbofan,* and it is widely used on commercial airliners.

In the early days of jet development, the turbojet engine used a great amount of fuel. Continued research, however, has made its operation much more economical. Fuel consumption in this type of engine is measured by the kilograms of fuel required to create one kilogram of thrust for an hour. Today the consumption rate is not much higher than the comparable rating of a piston engine.

Fritz Henle/PR

Technicians check and service a jet engine to make certain that it is in good flying condition. Raised cowling reveals part of the interior.

Speed is the major advantage offered by the turbojet type of engine, although up to the present time such speed has been obtained at the expense of range. Today there are several types of jet-propelled craft capable of exceeding the speed of sound in level flight.

Turboprops. A variation of the turbojet principle is the turboprop, or turbine-propeller, engine. The intake, compressor, combustion, and turbine units are like those of the turbojet. The difference is that most of the energy released by the escaping gases is used to drive a propeller. Some of it, however, provides thrust as the gases escape. Thus, propeller drive and exhaust thrust are provided by a single engine.

Lockheed Aircraft Company

Wing flaps lowered for takeoff, a Lockheed TriStar rises into the air with the thrust of its three turbofan engines, each of which provides 19,050 kilograms of thrust. The plane can carry a maximum of 400 passengers.

The turboprop represents a compromise between the jet and the piston engine. It is slower than the jet but uses less fuel. It is faster and freer of vibration than the piston motor. It burns more fuel than the latter, but it can use low-grade fuel, costing less than aviation gasoline.

Jet and turboprop airplanes are used for different purposes. The large turbojet serves particularly for long-range and intercontinental flights or for shorter hauls with large passenger and freight loads. The principal application of the turboprop and the small turbojet is in short-range and medium-range flight, where high speed is not so necessary. Turboprops use less fuel than turbojets, and generally they do not require very long runways.

Ramjets. The ramjet, or "flying stovepipe," is the simplest of the jets that draw in air, since it has neither compressor nor turbine. Essentially it is a long tube containing a fuel-injection system and a spark plug. To work effectively, the ramjet must be moving at a high speed. To operate most efficiently, it must travel at speeds in excess of Mach 2. *Mach,* or the *Mach number,* named after the Austrian physicist Ernst Mach, is the ratio of the speed of a body to the speed of sound in the surrounding atmosphere. Therefore, Mach 2 is twice the speed of sound.

Compression is provided by the so-called ram effect—that is, the sudden compression of the air as it enters the tube at high velocity. No mechanical compression is required. The compressed air passes through the combustion chamber. There the burning fuel creates the working gas, which is expelled rearward as thrust. Ramjets are capable of far greater power than anything yet attained by turbojets, but they also have a very high rate of fuel consumption.

Because of the high speed required for ram compression, the ramjet has as yet found little application in manned aircraft. For one thing, having no mechanical compressor, it is incapable of taking off from the ground—that is, at zero speed. It does, however, have an application in guided missiles, which operate within the atmosphere. A missile of this sort is fired from the ground, using a rocket engine for the takeoff. By the time the rocket fuel is exhausted, the missile has attained a speed at which its ramjets can operate efficiently and propel it through the air.

JET PROPULSION TODAY

Jet power, once developed, was applied at a rapidly increasing rate to commercial aviation. Today giant turboprop and turbojet airliners can carry up to 400 or more passengers each, on sustained flights of thousands of kilometers and, in some cases, at velocities exceeding that of sound.

Great Britain was the pioneer in the turboprop field. In 1950 Vickers Armstrong brought out the Viscount, a four-engine turboprop transport that became highly successful in Europe and in North America. The Viscount model 840 seated up to 75 passengers. With its four 2,080-metric-horsepower Rolls-Royce engines, it cruised at 640 kilometers an hour. The maximum range was 2,650 kilometers.

About a quarter of a century later, a comparable leader in the field of British commercial aircraft was the British Aircraft Corporation's BAC One-Eleven, Series 500. The twin-turbofan transport can seat up to 119 passengers and ordinarily cruises at about 740 kilometers an hour. Its maximum range is about 3,480 kilometers. When the BAC One-Eleven first appeared in the 1960's, it was one of the first commercial jet aircraft to have rear-mounted engines in order to reduce noise in the passenger cabin.

Other countries followed Britain's lead in the jet race. For example, in the United States, the Boeing Company flew the first American jet-powered commercial transport—the 707 prototype—in 1954. Several different models of this four-engine plane came to be used by a number of airlines the world over. Boeing's giant in the field of commercial aviation today is the 747, which can seat nearly 400 people. Powered by four turbofan engines, it cruises at nearly 1,000 kilometers an hour and has a range of about 10,000 kilometers.

THE SST CONTROVERSY

A number of other countries are also producing large and small jet-propelled aircraft. The most striking development in this area in recent decades—and the most controversial—has been the appearance of the supersonic transport, or SST. Such aircraft are designed to fly at altitudes of more than 18,000 meters and at speeds in excess of 2,000 kilometers an hour. Three nations are now involved in the SST venture: the Soviet Union, with its TU-144; and Great Britain and France, with their *Concorde*. The United States had developed plans for an SST as well, but then abandoned them—partly because the public decided that the value of the new plane was not great enough to outweigh the disadvantages described below. As a result, great controversy arose over whether or not to permit SST landings in the United States when the planes began to fly on a commercial basis. Regular service was at last permitted (beginning in 1977) at a limited number of U.S. airports.

The controversy involves several issues. One is the matter of increased noise, both around airports and along the flight paths of the SSTs. Another is the possible hazard the high-altitude flights of the SSTs present to the earth's ozone layer, which protects us from harmful radiation coming from the sun. Some people regard the SSTs as a costly waste of fuel for the sake of an hour or so less travel time. Others see the swift aircraft as the next logical step in the development of jet-propelled flight.

Whatever is made of the SST issue, as the world moves into the era of supersonic and space flight, jet and rocket engines will undoubtedly be used to a greater extent, wherever very high speeds are necessary and wherever it is impossible to use propeller-driven craft.

The practical use of atomic power in jet and turbojet machines has still not been realized, but experiments go on. A small nuclear reactor will probably heat air or water to operate the engines, so that a plane will be able to fly around the world without stopping to refuel.

Cliches Aerospatiale Air-France

Supersonic planes for commercial use are now in service. These planes can cross the Atlantic in about $3^1/_2$ hours.

SUPERSONIC FLIGHT

by E.V. Laitone

The term *supersonic* refers primarily to the flight or motion of any solid body through a gas at a velocity that exceeds the velocity of sound in that gas. When we speak of sound in this connection, we have in mind the pressure variations that move outward in all directions, in the form of waves, from a disturbance such as the tooting of a horn or the roar of a lion. The waves in question are usually very weak. When they strike our eardrums, they set up vibrations that are recorded in the brain so that we hear the disturbance that set off the waves. These pressure variations, or *sound waves,* as they are generally called, exist whether or not they strike our eardrums and result in the sensation of hearing.

Sound waves traveling through the atmosphere near the earth's surface have a velocity that decreases continually with altitude. It ranges from 340 meters per second at sea level, under standard conditions of temperature and pressure, to 295 meters per second at an altitude of 11,000 meters. Then it remains constant to 25,000 meters altitude, after which it starts to increase.

Suppose that the velocity of sound in the atmosphere at a given altitude is 1,100 kilometers per hour. A plane traveling at 2,200 kilometers per hour is moving twice as fast as the velocity of sound. We would say that it has attained a supersonic velocity of twice the speed of sound. Supersonic velocities are not restricted to solids traveling through gases. Strong sound waves, such as those set up by an explosion, travel at a velocity greater than the very weak sound waves that we described above.

MEASURING SPEED

The speed of any supersonic flow is usually given in terms of the *Mach number,* named after the 19th century Austrian physicist Ernst Mach. The Mach number represents the ratio of the speed of a body to the speed of sound in the surrounding atmosphere. The speed of sound, or *sonic speed,* is Mach 1. The expression "Mach 2" applied to a supersonic aircraft means that its velocity relative to the atmosphere is twice the velocity of sound passing through the atmosphere.

The Mach number can also be applied to subsonic speeds—that is, speeds less than the speed of sound. In this case, also, it represents the ratio of the speed of a body to the speed of sound in the atmosphere. The Mach number, in the case of subsonic

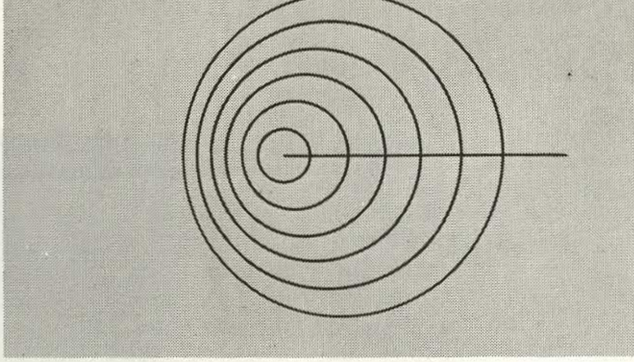


Fig. 1. At subsonic speeds, the pressure waves travel faster than the body producing them. They become closely spaced ahead of the moving body and expand behind it.

speeds, is always less than 1. For instance the Mach number 0.9 refers to flight at nine-tenths the speed of sound.

A plane traveling at subsonic speed is preceded by the sounds or pressure waves that are caused by its flight. But since a plane in supersonic flight travels faster than sound, it gives no advance warning of its coming. In other words, it is preceded by a *zone of silence*.

At subsonic speeds, then, the sound or pressure waves travel faster than the body producing the waves. The waves spread out. They become closely spaced ahead of the moving body and they expand behind it, as shown in Fig. 1. To a stationary observer, there are more waves per second ahead of the approaching body causing the waves. Therefore, the frequency increases. There are fewer waves per second behind the body leaving the stationary observer, so the frequency is decreased. This is the familiar *Doppler effect*. It accounts for the fact that a train whistle has a higher frequency (that is, has a higher pitch) upon approaching than it does upon leaving.

At supersonic speeds, the sound source travels at a speed greater than the velocity of sound propagation and would tend to produce the wave pattern shown in Fig. 2. Note that the sound waves would begin to be propagated after the object had passed by a given point. Since time would be consumed while the body traveled, the oldest of the waves would have the largest radius at any given moment, while the most recent wave would have an extremely small radius. In either case, the waves at any given moment would be limited by the zone of silence. They would form a cone called a *Mach wave*, bounded by the zone of silence. The Mach wave is also known as a *Mach cone* and *Mach envelope*.

As the Mach number increases—that is, as the velocity of supersonic flight increases—the cone becomes progressively narrower. It becomes progressively wider as the Mach number decreases. Finally, when the Mach number is 1—that is, when the object is traveling at the speed of sound, the Mach wave is no longer a cone but more nearly a plane at right angles to the direction of motion (Fig. 3).

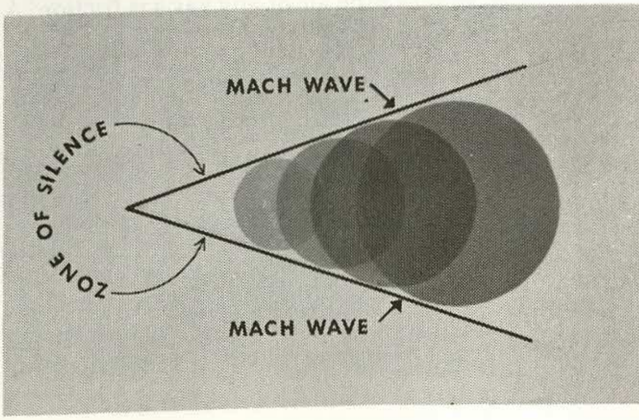


Fig. 2. At supersonic speeds, the pressure waves are propagated after the body producing them passes by a given point. They form a cone that is called the Mach wave.

Suppose an airplane traveling at subsonic speed dives toward the earth. It may attain sonic speed during the dive pull-out. The pressure disturbances can pile up at the Mach wave or envelope, which by this time resembles a plane at right angles to the line of flight (Fig. 4). After the airplane has recovered from its dive, this envelope can continue downward until it reaches the ground and can make itself felt as a disturbance, called a *sonic boom*.

A plane traveling at supersonic speeds can bring about a supersonic boom even in steady, level flight. This cannot occur at subsonic speeds, since the increase in pressure produced as the plane passes through the air is spread over an unlimited area, and therefore results in a very small increase in pressure over the earth's surface. However, at supersonic speeds the pressure increase can be propagated only behind the

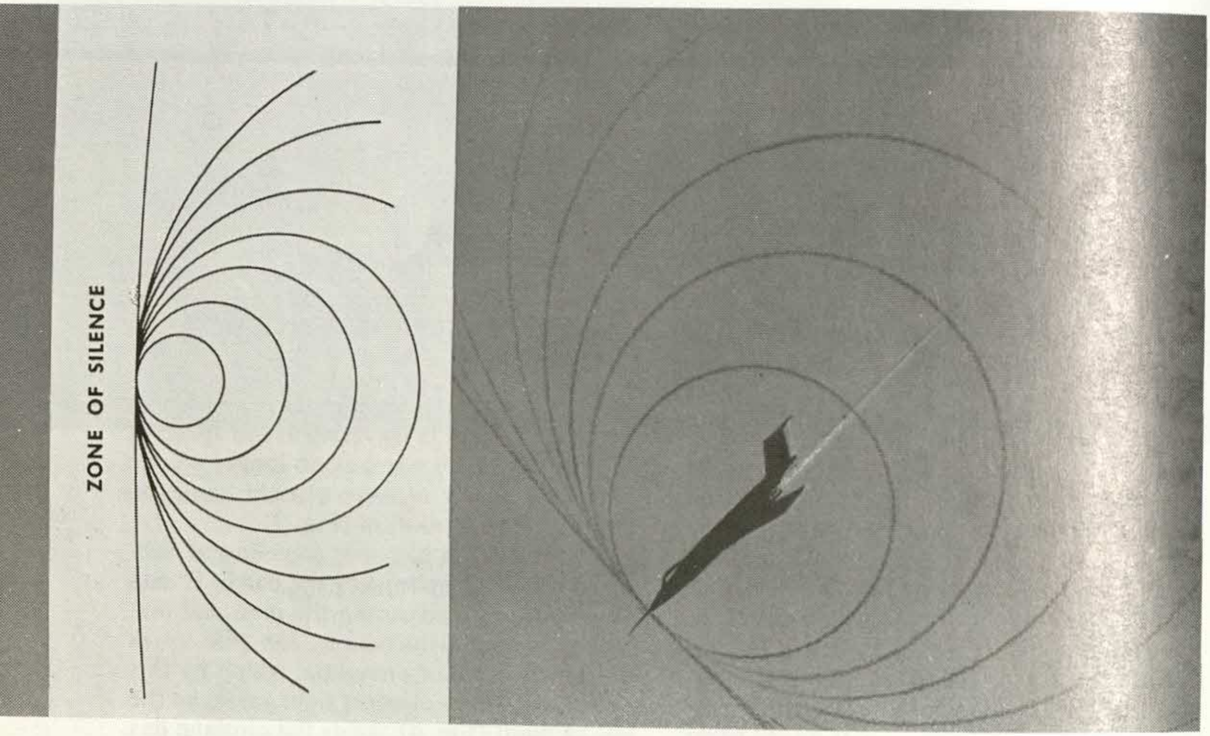


Fig. 3. (Inset) When an object travels at the speed of sound, the Mach wave is very nearly a plane at right angles to the direction of motion. Fig. 4. After the plane pulls out of the dive, the Mach wave continues toward earth.

envelope bounded by the zone of silence. It is this concentration of the pressure disturbance that can produce a supersonic boom. If the airplane is flying very low, the pressure concentration can be serious enough to damage an ordinary roof top.

DRAG FORCES

An object moving forward through the air is retarded by it to a greater or lesser extent, since the air or any gas has friction. A plane in subsonic flight is preceded by the pressure waves it creates as it makes its way through the air. These pressure waves push away the air in front of the plane and there is less *drag* than would otherwise be the case. But when the plane reaches sonic speed, or the speed of sound, the pressure waves no longer precede the plane. They no longer push away any of the air in front of the craft and the drag forces become much greater. The large drag rise as the plane approaches Mach 1, or the speed of sound, is generally referred to as the *sonic barrier*.

Even a conventional subsonic plane traveling at a speed below Mach 1 can encounter an extreme rise in drag. This is why. As the wing moves through the air, the pressure over the wing is decreased. This results from the increase in the speed of the air stream over the wing in accordance with the law of physics called *Bernouilli's principle*. Because the pressure decreases, the temperature is also lowered. Now the increase in velocity of the airflow over the wing directly increases the local Mach number—that is, the speed at this particular place, while the decrease in temperature of the air flowing over the wing directly decreases the local speed of sound. This leads to a still greater increase in the local Mach number, since this number indicates speed in relation to the speed of sound. Eventually, if the plane is going fast enough, the local Mach number will become supersonic, even though the flight Mach number remains subsonic—that is, even though the plane is still flying at a speed less than that of sound.

When this condition is reached, a shock wave arises and returns the flow over the wing back to subsonic conditions. The local shock wave on the upper surface of the wing reduces the lift. It can also cause the airflow to separate from the wing and can produce a severe buffeting of the rear tail surfaces. To avoid such buffeting, the rear tail surfaces are generally raised quite high behind the wing of an airplane that travels at speeds approaching the speed of sound.

This high-tail position is not altogether effective. The airflow disturbance caused by the shock waves mentioned above lessens the so-called "downwash" on the tail and thereby increases the *static stability* of the airplane. By static stability we mean the tendency of a plane to point itself automatically in the wind, like a weathervane. This makes the craft more difficult to maneuver. In some cases it has been found impossible to pull an airplane out of a high-speed dive with the available elevator-control surface motion. This can lead to rather disastrous results.

MOVING THROUGH TRANSONIC RANGE

A supersonic aircraft is confronted by much the same difficulties as it moves through the *transonic range*—that is, the range of speeds from slightly less than Mach 1 to slightly greater than Mach 1. Hence it generally tries to pass through this range as quickly as possible.

Supersonic aircraft are provided with swept-back wings as indicated in Fig. 5 in order to minimize adverse effects on control and stability. Up to a certain speed the Mach waves produced by each segment of the swept-back leading edge (the foremost edge) of the wing push back much of the air in front of the plane. The flow can then proceed smoothly about the remainder of the wing without forming a shock wave (Fig. 6). As the flight Mach number increases, the Mach waves eventually become parallel to the fixed leading edge. By then shock waves have formed on the wing, as shown in Fig. 7. Hence, the degree of sweepback on the wing is dictated by the flight Mach number desired. The higher the Mach number, the greater the degree of sweepback.

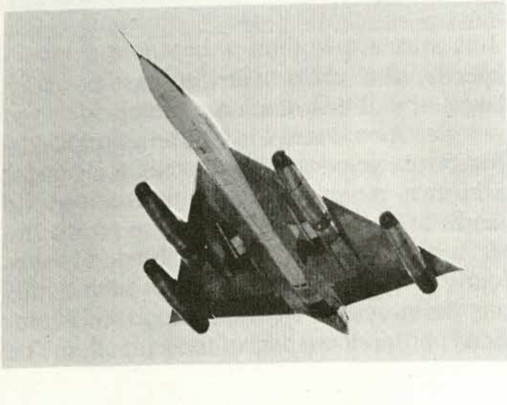
The leading edge of a swept-back wing actually performs best even at supersonic flight speeds if it is rounded, but only if the Mach waves lie ahead of the leading edge, as in Fig. 6. When the leading edge lies ahead of the Mach waves, as in Fig. 7, it must be razor sharp in order to decrease the shock-wave losses. The nose of such a plane must be as sharply pointed as possible (Fig. 8).

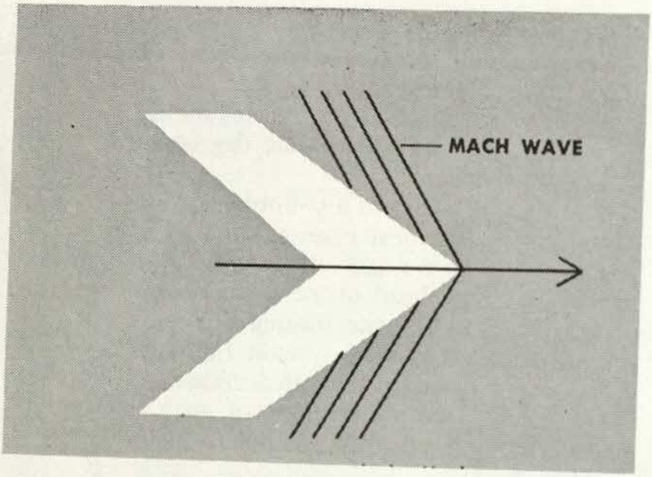
TESTS ON SUBSONIC AND SUPERSONIC FLIGHT

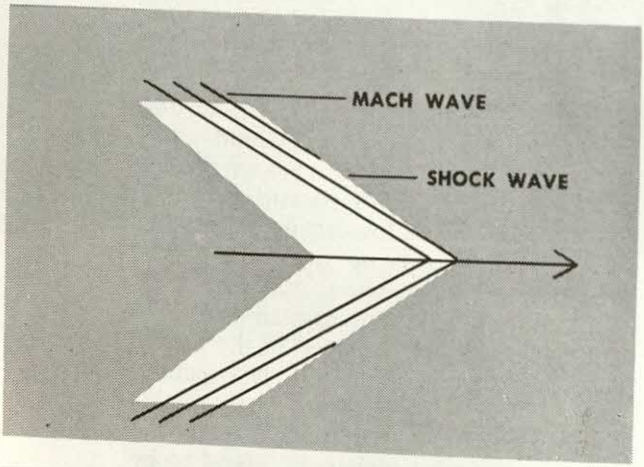
Much of our knowledge of the phenomena of subsonic, transonic, and supersonic flight is derived from tests carried out in *wind tunnels*. The apparatus shown in Fig. 10 can be used for subsonic wind-tunnel tests for speeds up to Mach 1. The airflow is nearly always maintained by means of a propeller downstream at *C*. The wind-tunnel model is placed in the nozzle throat (*B*), which is called the test section. The size of the nozzle throat varies, in different installations, depending upon the speed desired; the higher the speed to be tested, the smaller the test section. For tests of speeds approaching Mach 1, the cross section of the nozzle throat is only a square meter or so in area. At low, subsonic

Fig. 5. Supersonic aircraft are provided with swept-back wings to ensure control.

U.S. Air Force Photo







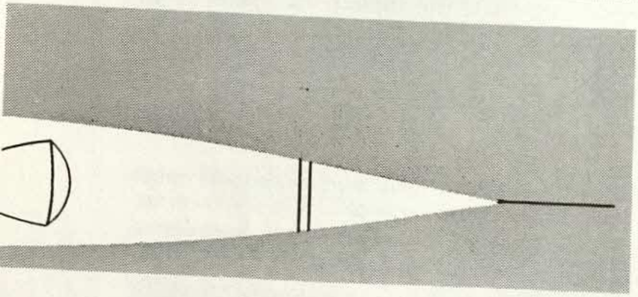


Fig. 6. Up to a certain speed, the Mach waves push back much of the air in front of the plane; hence no shock waves are formed.

Fig. 7. As the flight Mach number increases, the Mach waves become parallel to the leading edge of the wing; shock waves are formed.

Fig. 8. The nose of a plane designed to travel at high supersonic speeds must be as sharply pointed as possible for maximum efficiency.

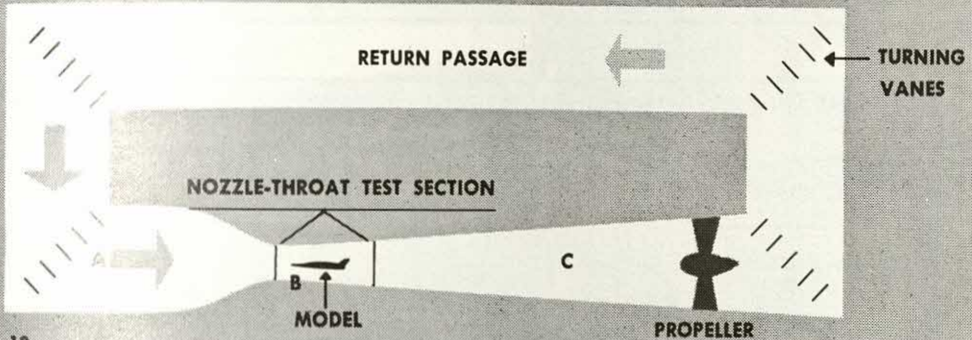
speeds, the cross section can be very large—hundreds of square meters.

Sections *A* and *C* of the wind tunnel, in Fig. 9, are generally connected by means of a return passage. This contains turning vanes at each corner in order to return the air supply smoothly from *C* to *A*. The velocity in a subsonic wind tunnel such as this can be increased by increasing the revolutions per minute (rpm) of the propeller. The highest Mach number in the nozzle throat is limited to unity (1).

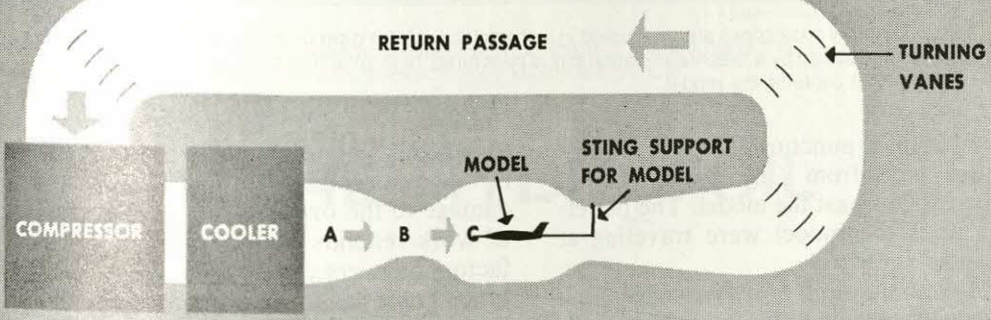
To test aircraft flying at supersonic speeds, a wind tunnel such as that in Fig. 11 is used. In this case, section *C* is the test section. Because interference effects become greater as a plane attains supersonic speed, the mounting of a model in a supersonic wind tunnel offers considerable difficulty. Generally the model is set on a long sting, or boom, which extends quite far downstream behind the model. The boom contains a series of gauges which measure electrically the stresses produced in the simulated supersonic flight.

If the area at *C* is decreased, the supersonic Mach number is decreased and the required operating pressure is higher. If the area at *C* is increased, the Mach number is also increased and the required operating pressure at *C* is lower. Hence supersonic wind tunnels that attempt to run tests at several Mach numbers must possess the equipment to vary the cross-section area at *C* as well as the operating pressure. This is generally done by increasing the pressure at *A* by means of air compressors, as shown in Fig. 10, while the area at *C* is altered by having a flexible or movable section between *B* and *C*. Great care must be used in making the necessary adjustment in cases such as these.

Supersonic wind tunnels require considerably greater metric horsepower for steady operation than do subsonic wind tunnels. The power requirements range



10.



11.

Fig. 9. This wind tunnel is used to test aircraft performance at subsonic speeds, up to Mach 1. The test model is set at B; the higher the speed, the smaller the test section.
Fig. 10. Wind tunnel designed to test the performance of aircraft flying at supersonic speeds. To counteract interference effects, the model is mounted on a sting, or boom.

from 1,000 metric horsepower for a 23-centimeter test-section diameter, to 60,800 metric horsepower for the three square meter test section of the supersonic wind tunnel at the Ames Aeronautical Laboratory of the NASA at Moffett Field, California.

EXPERIMENTAL TESTS

The speeds and the temperatures encountered by the re-entry nose cone are so high that at present experimental tests can be carried out only on an extremely small scale. Most of these tests are performed in an apparatus called the *shock tube* (Fig. 11), which consists of a long pipe with a small diameter. A very small nose-cone model is mounted in the low-pressure end. This is temporarily shut off by a thin metal or plastic diaphragm from the high-pressure gas in the high-pressure chamber. The pressure ratios between the low-pressure and high-pressure parts of the pipe range from 1 to 100 to something like 1 to 10,000, in order to simulate Mach numbers from 7 to 20.

When the model nose cone is ready for testing, a trigger mechanism is set off and

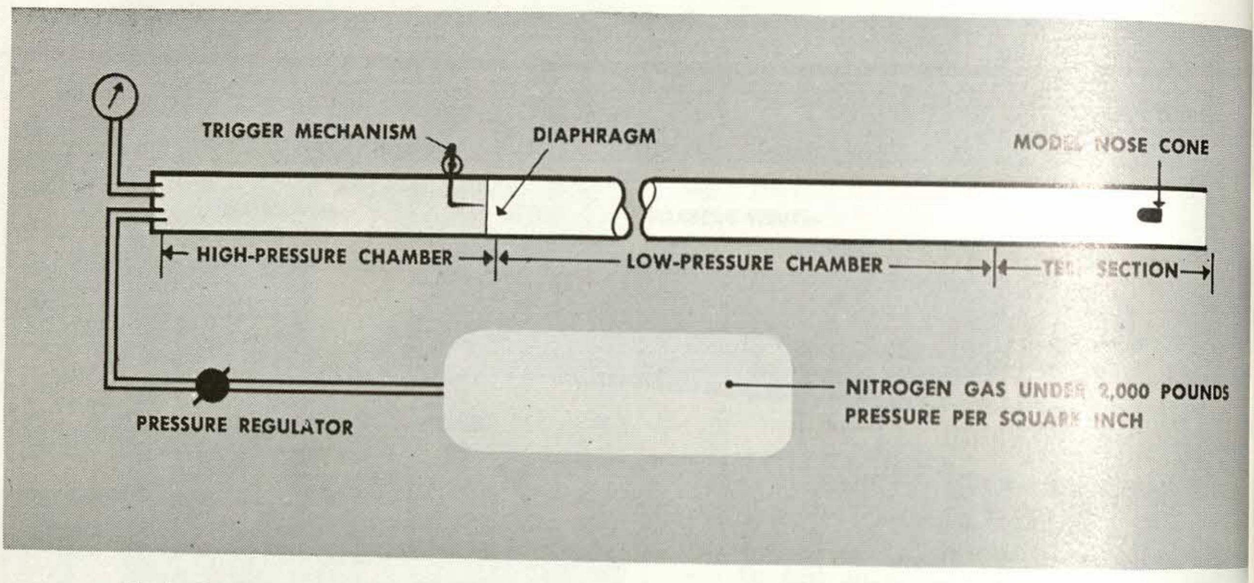


Fig. 11. Tests on re-entry nose cones are conducted in a shock tube, a long pipe of small diameter. The tube is blocked up by a diaphragm; when this is punctured, high-pressure gas rushes into the chamber that contains the model.

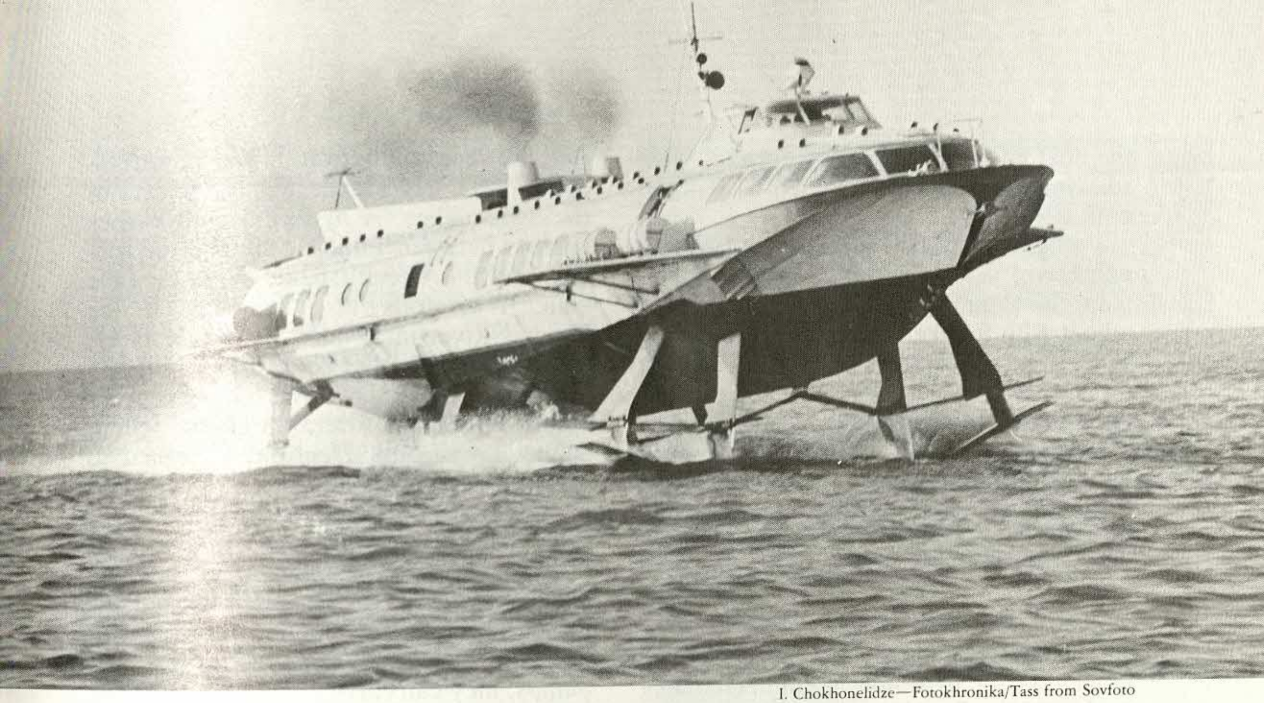
the diaphragm is punctured. A slug of high-pressure gas from the high-pressure chamber rushes past the model. The net effect is as if the model were traveling at hypersonic speeds.

Supersonic craft for passenger use have been developed by Great Britain and France. These planes carry passengers across the Atlantic in only about $3^1/_2$ hours. The possibility of supersonic passenger planes making regular schedules has, however, caused a great deal of controversy, much of it centered in the United States. Many people fear that the increased use of supersonic planes could cause serious damage to the environment—for several reasons.

Supersonic planes fly at very high altitudes where their exhausts can affect the ozone layer of the atmosphere. The ozone layer surrounds the earth, protecting it from the sun's ultraviolet radiation. Damage to this layer could, according to some researchers, lead to an increase in skin cancer and to possible long-term climatic changes. There is no doubt that such effects would occur were the ozone layer in fact totally destroyed. However, there is a great deal of doubt among researchers as to whether numerous high-altitude flights by supersonic aircraft could cause such damage to the ozone layer. A vast amount of work remains to be done before satisfactory answers can be given to such questions. Opposition to supersonic aircraft on this point is in the nature of a precautionary measure—that is, we should be cautious about what we might be doing to the ozone, rather than being sorry later.

There are several other environmental issues that also must be considered. Supersonic planes are less fuel efficient than conventional passenger jets, and the world's supply of fuel is limited.

The noise produced by supersonic planes is, however, the environmental issue that has attracted the most public interest. Supersonic planes are noisier than conventional jets. However, reports on how much noise levels would be increased by the flight of a limited number of these planes are not in agreement. People living in areas surrounding airports at which supersonic passenger planes would take off and land have voiced strong objections to the flight of these planes. At present the ultimate success of routine supersonic passenger flights is questionable.



I. Chokhonelidze—Fotokhronika/Tass from Sovfoto

When hydrofoils travel at high speeds, the main body of the ship is lifted out of the water. This Soviet hydrofoil can reach speeds of 65 kilometers an hour.

THE HYDROFOIL

"A boat that flies through the water on wings"—that is an apt description of the hydrofoil, or hydrofoil boat. This graceful craft has been hailed as the most revolutionary development in marine engineering since steam was first used to propel ships. Its wings are known as *foils*, or *hydrofoils* ("water wings"), because of their resemblance to the airfoils ("air wings") of an airplane. The wings of a hydrofoil craft are attached to struts which extend downward from the hull. There are two sets of foils. One set is located forward of the boat's center of gravity. The other set of foils is near the stern.

When traveling at slow or moderate speeds, a hydrofoil operates like a conventional boat, with its hull partly immersed in the water. As the craft picks up speed, water is deflected from the upper surfaces of the foils, just as air is deflected from the upper surface of an airplane wing. The water pressure on the top foil surfaces decreases and this lessened pressure creates lift. As more and more lift is produced, the prow emerges from the water. Finally, the entire hull rises clear of the surface. It becomes "foil-borne." In some types of hydrofoil craft, the foils remain fully submerged at all times. In other types, they are only partly submerged when the boat is "flying." When speed slackens, the pressure on the upper wings increases and the lift is diminished. Finally, the hydrofoil becomes water-borne again.

FAST AND SMOOTH

Because the hull remains above the surface while it is foil-borne, it escapes the drag of surface friction, and it does not have to fight the bow waves that a conventional surface craft creates in front of itself. Hence a hydrofoil can go two or three times faster than a conventional surface craft of comparable size and horsepower. Since the hull is not subjected to surface turbulence, the boat gives a smooth ride even in rough seas, unless the waves are larger than the craft itself.

The idea of the hydrofoil goes back a number of years. In 1887 a French nobleman, the Count de Lambert, demonstrated a boat with foillike structures on the Seine River. The newspapers of the day reported the event, but little more was heard thereafter about Lambert's craft.

The first really successful hydrofoil boat was built in 1905 by the Italian Enrico Forlanini. It attained a speed of 75 kilometers an hour. In 1919 the U.S. inventor Alexander Graham Bell and his associates constructed a 4.5-metric-ton hydrofoil boat, which is said to have raced along at up to 130 kilometers an hour. The modern development of the hydrofoil began in Germany in the 1930's. By 1945, nine different types of hydrofoils, with displacements of from less than one to about 55 metric tons, had been built and tested.

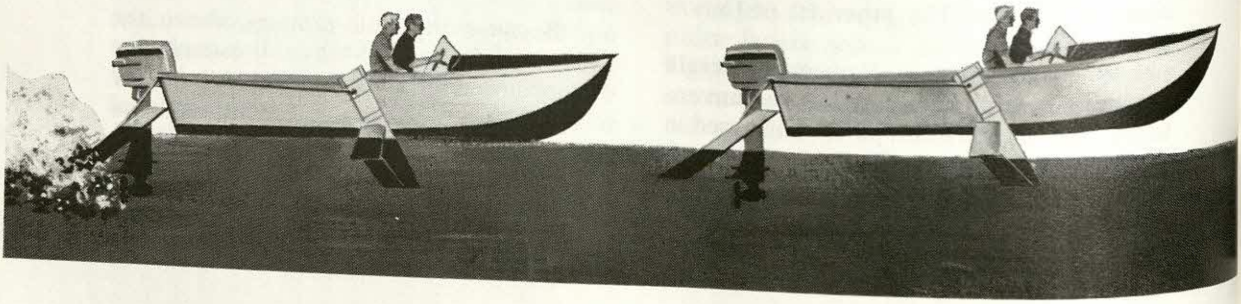
Hydrofoils are now being used to carry passengers on a number of the world's waterways. An oustanding hydrofoil craft is the Soviet *Meteor*. Carrying 150 passengers, it has been plying for some time between Gorki and Ulyanovsk, on the Volga River, and has attained cruising speeds of 70 kilometers an hour. Other hydrofoils besides the *Meteor* are in operation on the Soviet Union's lake and river systems. Italy has also developed some remarkable passenger-carrying hydrofoils. The *Freccia del Sole* transports passengers in comfort across the choppy Strait of Messina. The *Freccia del Garda,* another passenger hydrofoil craft, operates on Lake Garda, in northern Italy. Other Italian boats make runs between southern Italy and various Sicilian ports. Hydrofoils ply the waters of the Swiss lakes. A hydrofoil craft carries tourists between Piraeus, the port of Athens, and the Greek islands in the Saronic Gulf. Hydrofoils also operate on the Thames River in London, and in Norway, Venezuela, and other countries.

U.S. commercial hydrofoils have included Grumman Aircraft's 80-metric-ton, 30-meter hydrofoil *Denison*. Designed to carry 80 passengers at speeds up to 150 kilometers per hour, it was used in a series of tests and then turned over to the U.S. Navy. The first of several Boeing Jetfoils, launched in 1974, is 27 meters long and displaces 96 metric tons. Jetfoils are built for use in rough waters. Powered by water-jet pumps, they can carry 250 passengers at 80 kilometers per hour on retractable foils.

POSSIBILITIES

It is believed that the hydrofoil may help solve the increasingly serious commuting problem in certain U.S. cities lying along the coast or on rivers or lakes. At the present time, however, hydrofoils in the United States serve chiefly as pleasure craft. Several U.S. manufacturers are offering hydrofoil-equipped boats, and sales are rapidly increasing. Hydrofoil kits are also available for converting conventional boats into hydrofoil craft. The kits include two main foils and a tail foil, which can be easily mounted and removed. Even sailboats utilizing the hydrofoil principle have been developed.

There are other uses for hydrofoil craft. Transoceanic hydrofoil liners of up to 1,000 metric tons would provide smooth

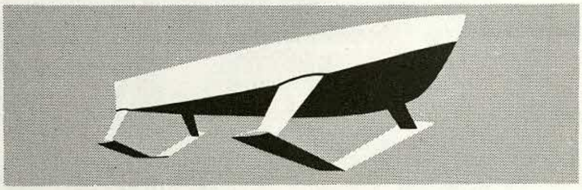


passages in rough seas and would lop days off the sailing times of even the fastest modern liners. Hydrofoils make ideal boats for harbor police and pilots and for the customs service. They could be used profitably by industries in which workers and materials have to be moved quickly. They could render valuable service, too, in the transport of perishable goods in quantity, particularly in tropical waters.

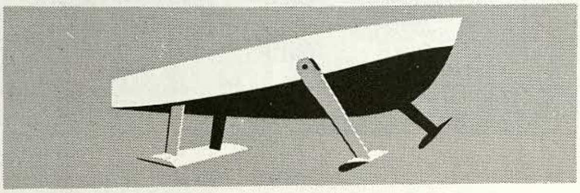
The hydrofoil has interesting possibilities in military operations. Atomic-powered submarines can reach speeds of 55 kilometers an hour while fully submerged and are highly maneuverable. Conventional destroyers and patrol boats would find it hard to cope with them. The hydrofoil, however, would be ideally suited for service against atomic submarines. It would be more than a match for a submarine of this type in both speed and maneuverability. Besides, it could operate with little reduction of speed in rough seas that would considerably slow down the ordinary destroyer or patrol boat.

The thrust of the U.S. Navy hydrofoil program has been toward larger and faster vessels. Beginning with the small research ship *Sea Legs* and the very successful 52-metric-ton gunboat *Tucumcari,* the Navy program has seen development of the 118-metric-ton *High Point,* the 235-metric-ton missile ship *Pegasus,* and the 290-metric-ton U.S.S. *Plainview,* used by the Navy as a hydrofoil research platform. Later ships are expected to exceed 1,000 metric tons' displacement and 125 kilometers per hour.

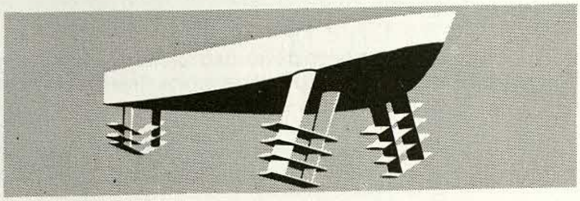
Even though numbers of hydrofoil-equipped craft are in active use today, the hydrofoil is rather a boat of the future than



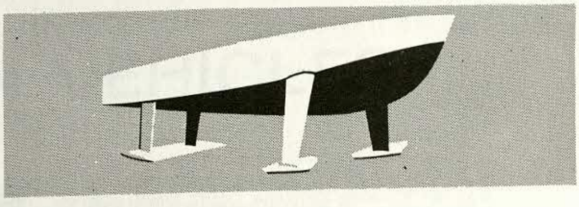
Foils V-shaped and partly submerged at bow and stern.



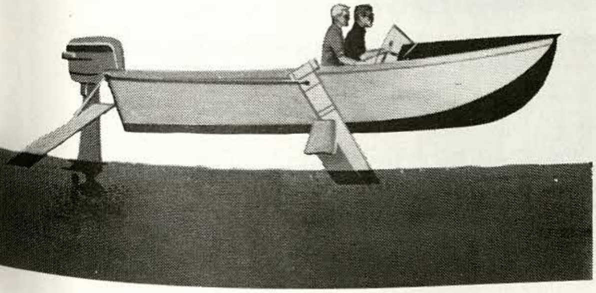
Foils submerged partly at bow and fully at stern.



Foils arranged in ladder fashion at bow and stern.



Foils are fully submerged at both bow and stern.



How a hydrofoil becomes "foil-borne." At first the hull is partly submerged. As the boat accelerates, the lift provided by the foils causes the hull to rise above the surface of the water. Above: important hydrofoil types.

Pictorial Parade

The graceful Soviet-built hydrofoil craft *Solyom* provides passenger service on the Danube River in Budapest, Hungary.

of the present. Engineers are still seeking to solve certain troublesome problems that have hampered the full development of the craft. For one thing, there is the phenomenon of *cavitation*, which arises when speeds of from 110 to 150 kilometers per hour are attained. In cavitation, the low water pressure at the top surface of the wings drops until it changes to vapor pressure, and this leads to the formation of areas of partial vacuum, that appear as bubbles. When the bubbles wander to the high-pressure area at the rear of the wings, they collapse and create turbulence. Considerable progress has been made in coping with this phenomenon, but it still imposes a limit to the speeds that a hydrofoil can reach.

Hydrofoils have been developed for military maneuvers as well as for pleasure boating. The main attractions for hydrofoil fleets are the ships' speed and maneuverability. They also operate well in rough seas.

British Hovercraft Corporation Ltd.

Airplanes are not the only vehicles to ride on air. This large ship is a hovercraft, or air-cushion vehicle. It is pushed by the large propellers that sit on top.

AIR-CUSHION VEHICLES

If someone told you that a train could literally fly over the rails, perhaps you wouldn't believe him. What if he then told you that a ship can cross a stretch of ocean without touching the water? You still might not believe him.

Start believing. Such craft, called air-cushion vehicles, do exist.

An *air-cushion vehicle*, or ACV, is a machine designed to operate on a cushion of air at a height of a few centimeters above the surface of ground, rails, or a body of water.

The air cushion is provided by one or more powerful fans whirling on a vertical axis and directed downward. Forward motion and braking are supplied by horizontally mounted propellers or turbines. In

This "surface effect ship," as it is called by the U.S. Navy, heads out for a test run. Some seagoing ACVs can reach speeds of 185 kilometers per hour.

Bell Aerospace Division of Textron

both photos, Bell Aerospace Canada, a division of Textron Canada Ltd.

Seagoing air-cushion vehicles are very useful in harbors and marshes. Since ACVs do not sit in the water, they can travel over shallow areas. Some can even travel from land to water and back again.

other types of ACVs, air moved by fans through side ports provides horizontal propulsion, braking, and control power.

Air-cushion trains are propelled by turbines or by a device known as a *linear-induction electric motor*. The tracks are actually part of the motor system. Coils in the ACV generate a magnetic field that actually moves the train horizontally on its air cushion along the tracks. Air-cushion trains have been developed in the United States, Great Britain, France, and the Soviet Union. Some experimental vehicles of this type achieve speeds of up to 290 kilometers.

Seagoing ACVs reach velocities of as much as 100 knots. They can also be operated over beaches, tidal flats, and shallows. Others can move up onto the land if the terrain is not too rugged.

The air-cushion principle has been extended to wheeled vehicles, where it supports about 75 per cent of the weight of the vehicle. Such semi-ACV types can easily move over rough country or on wet or water-logged ground.

NCR Corporation Photo

Advances in electronics reach the average consumer very quickly. This register is equipped with scanning systems that automatically record and tally purchases.

AN INTRODUCTION TO ELECTRONICS

Rarely has a technological development had as great an impact on as many aspects of social, economic, and cultural development as the rapid growth of electronics. Electronic devices affect our lives in many ways. There is hardly a tool or appliance or item of transportation or communication that in one way or another does not rely on electronic technology. Our timepieces record time more accurately, our homes are heated or cooled more efficiently, and our industries and health-care facilities serve us better because of the technological advances in the field of electronics that have occurred over the past several decades.

The revolution in technology stems from the scientific discovery of electrical particles. The control of these electrical particles, known as *electrons,* forms the basis of the vital science of electronics and of its numberless applications.

Electronics is a development of the 20th century. Many devices operated by means of electric currents were in use before the beginning of the century. They included the electric motor, the telegraph, the telephone, and the electric light. But until science discovered the electron, people had no idea that electric currents simply represent the flow of electrons. Today we realize this fact, and we also know that streams of electrons may flow inside or outside a conductor. Therefore, we reserve the term ''electrical'' for devices such as the electric motor, the telegraph, and the telephone where the stream of electrons flows in a conductor. The term ''electronic'' is

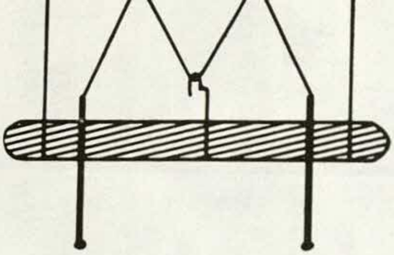


Fig. 1. Zigzag cathode.

applied to those devices in which the electrons are controlled as they move outside a conductor in a special kind of tube, called an *electron tube,* or else through a special kind of solid, called a *semiconductor* or *transistor*. Electric and electronic systems often interact.

There are many different kinds of electronic devices. We shall begin with the so-called vacuum tubes, in which electrons are controlled as they move about in a high vacuum.

THE DIODE VACUUM TUBE

The diode is the simplest vacuum tube. It contains only two elements—a cathode, the source of electrons; and a plate, or anode, the collector of electrons. The metal that constitutes the cathode is heated, and electrons are emitted from it. They form a fog that surrounds the cathode. Electrons have a negative electric charge. If the plate is positively charged, it pulls electrons away from the cathode. They are immediately replaced by other electrons emitted from the hot metal. These are pulled away from the cathode in their turn and are also replaced. The emission of electrons from a hot cathode is called *thermionic emission*.

There are several different kinds of cathodes. One type is quite similar to the filament of an ordinary incandescent lamp. It consists of a small-diameter tungsten wire bent in a zigzag or M shape in order to get more emitting surface in a small space (Fig. 1). When the tungsten filament is coated with thorium, it is called a thoriated tungsten filament. The emission of electrons is increased thousands of times, and the cathode can operate at a lower temperature. Both of these types are known as directly heated cathodes.

A third type of cathode consists of a core of platinum or nickel covered with a mixture of barium and strontium oxides. The cathode may be heated directly. In that case it is usually in the form of a ribbon. Generally, however, indirect heating takes place. The coating of oxides is applied to the outside of a tiny nickel sleeve—a hollow cylinder. Inside the sleeve is a coiled tungsten wire that is heated by an alternating current (Fig. 2). This wire heats the sleeve to a temperature at which electrons are emitted.

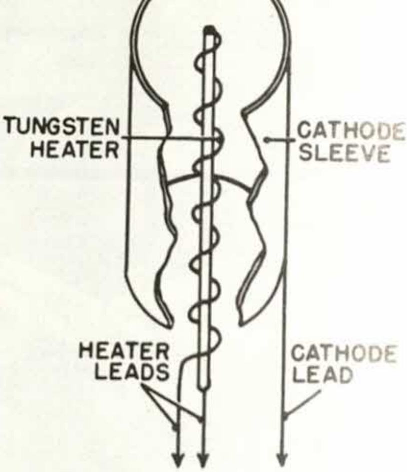


Fig. 2. Indirectly heated cathode.

The anodes are hollow cylinders that surround the cathode. In small tubes they are generally made of nickel; in larger ones, they are of molybdenum, graphite, or tantalum. The envelope—the outside of the tube—is cylindrical; it may be of heat-resistant glass, such as Pyrex, or of coated glass or metal.

Diodes can detect radio waves. As such they have played an important part in radio broadcasting, although they have now been superseded by transistors. The purpose of radio broadcasting is to transform audible sound waves, which are produced at the radio station, into radio waves. These are transmitted across great distances to the radio receivers and loudspeakers in our homes, where they are converted back into the original sound waves.

THE TRIODE VACUUM TUBE

The triode, or three-element tube, was invented in 1906 by Lee De Forest. It is still used in numerous electronic systems. In Figure 3 we show a simplified diagram of a triode. You will note that it has a cathode (K) and a plate (P) like a diode. It also has a

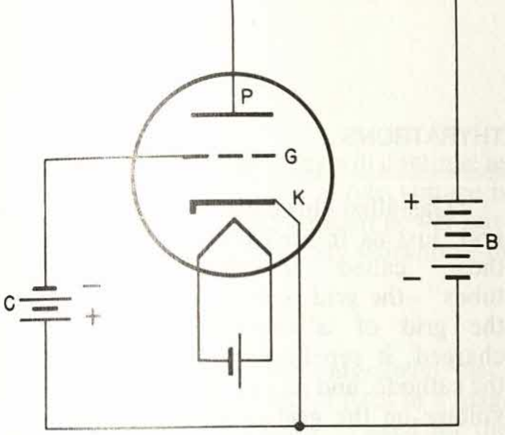


Fig. 3. The triode, a simplified version of which is shown here, was developed by the U.S. electronics pioneer, Lee De Forest.

third element, the grid (*G*), which is made of metal meshwork. The purpose of the grid is to regulate the number of electrons that will make the journey from the cathode to the plate. For the sake of simplicity, we have represented the three elements as lined up side by side in the tube. Actually, the cathode is in the center. It is surrounded by the grid, and the grid in turn is surrounded by the cylindrical plate. The grid is much closer to the cathode than it is to the plate.

In Figure 3, note that a battery (*C*) is set in the circuit between the cathode, *K*, and the grid *G*. If the grid is given a sufficiently strong negative charge, it will repel the electrons emitted by the cathode and will prevent them from reaching the plate. As the negative charge on the grid is decreased, electrons will flow to the plate. This flow will increase as the negative charge decreases. If a positive charge is applied to the grid, it will add to the attractive force exercised by the positively charged plate. The flow of electrons to the plate will be much greater than if there were no grid in the tube.

One of the most important tasks of the triode in electronic devices is to act as an *amplifier*—that is, to transform small voltages into much larger voltages, while reproducing all the fluctuations of the original. Small changes in the grid voltage will produce as much effect on the plate current as a change of many volts in the plate voltage. This increased current can easily be converted into a correspondingly great voltage. If a change of one volt in grid voltage has as much effect as a change of 10 volts in plate voltage, the tube is said to have an amplification factor of 10.

If the amplified output of such a triode were applied to the grid of a second triode, the combined amplification of the two tubes would be 100 times 100, or 10,000. A third tube would amplify this output another 100 times. We would then have a total gain of 1 million.

The triode tube also serves in oscillating circuits in which alternating currents are generated. It was used in this way for some time for radio broadcasting, for example. In radio we must have alternating currents with frequencies of hundreds of thousands or even millions of hertz. The generators in a power station could not produce anything like such frequencies. The alternating current they supply has a frequency of only 60 hertz. By using a triode in an oscillating circuit, alternating currents of millions of hertz can be generated.

MULTIELEMENT AND GAS-FILLED TUBES

The above descriptions of the diode and the triode provide a basic introduction to electron tubes. From the 1920's on, several other kinds of tubes have been developed that are more complicated in structure. Two examples are the tetrode and the pentode. They use one and two extra grids, respectively to deal with certain problems presented by the triode. Pentodes provide higher amplifications as well. Still more complex tubes with up to eight electrodes exist, along with combinations of these tubes in various arrangements. They continue to be used in detectors, amplifiers, oscillators, regulators, switches, and so forth.

In all vacuum tubes it was found that in order to attract electrons from the electron cloud surrounding the heated cathode, a high voltage is required. The reason is that once the flow of electrons between cathode and plate has started, the space within the tube has a strong negative charge. This tends to repel electrons from the cathode, and only a strong charge on the plate can counteract this repellent force. It was then found that if, after evacuating a tube, we admit controlled

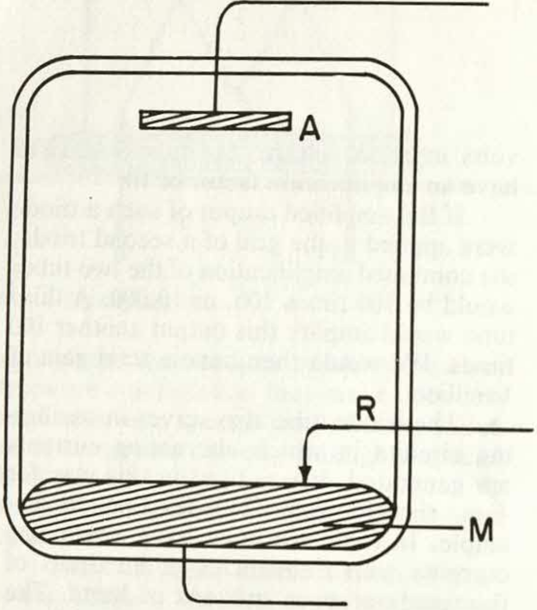


Fig. 4. An ignitron.

amounts of a gas—argon, neon, hydrogen, or mercury vapor—large currents could be carried with low applied voltages. This discovery led to the development of another great family of electron tubes, all filled with low-pressure gas.

How do gas-filled tubes work? When the cathode is heated, it emits electrons, of course, and these will be attracted to the positively charged plate, or anode. On their way to the plate they will collide with the atoms of the gas. They will break off electrons from some of the atoms, and will transform these atoms into positively charged ions. The electrons released from the gas atoms will join those streaming toward the positively charged plate. The positively charged ions will tend to neutralize the negative space charge, thus permitting more electrons to flow. As a result, much larger plate currents are possible than is the case with vacuum tubes. The gas tube may operate with quite low potentials on the plate—10 to 20 volts.

There are two main types of gas-filled electron tubes. Hot-cathode tubes use the gas to enable the tube to handle more current. Cold-cathode tubes use the gas to produce a glow lamp or to function as a switch or a voltage regulator. Glow lamps differ in color according to the gas with which the tube is filled. Neon is red, argon blue, and mercury blue-green.

THYRATRONS

Gas-filled three-element tubes have a grid, just as triodes do. Among them are those called thyratrons, or "door tubes"—the grid represents the "door." If the grid of a thyratron is negatively charged, it repels electrons emitted from the cathode, and no current will flow. As the voltage on the grid is made less negative, current will eventually flow through the tube. A visible glow will appear as the gas atoms are ionized. Once the plate current is started, the grid cannot regulate the amount of current flow as it can in the vacuum tube. The thyratron is not so flexible as the triode. Its chief advantage is that it can operate devices requiring current of many amperes.

A vacuum tube can be teamed up with the thyratron. The vacuum tube controls the voltage on the grid of the thyratron so that the latter will be turned on at a particular instant. Very tiny initial voltage impulses applied to the vacuum-tube grid can start the flow of currents of many amperes in the circuit of the thyratron. Such combinations are frequently used as fast operating relays to control many types of industrial devices.

IGNITRONS

In the electron tube called the ignitron, a pool of mercury serves as the cathode. A diagram of one type of ignitron is shown in Figure 4. The anode (*A*) is set opposite the mercury pool (*M*). A silicon carbide rod (*R*) makes contact with the pool. When current flows through *R* and its tip is raised from the mercury pool, a spark will jump from the silicon carbide to the pool. Electrons will then be knocked out of some of the mercury atoms in the pool. As these electrons travel toward the positively charged anode, they will collide with atoms in the mercury vapor that has formed above the pool. They will break off electrons from these atoms, which will become positively charged ions. The positive ions will be attracted to the negatively charged pool cathode. They will bombard the pool so heavily that additional electrons will be emitted. The whole process will continue as a chain reaction until the anode voltage is cut off. The ignitron has a high power output. It has been a heavy-duty workhorse of electronics.

OTHER ELECTRON TUBES

In the tube called the *magnetron,* electrons are whirled in a spiral path in a magnetic field. The magnetron is used for the generation and application of ultra-high frequencies. It made the development of high-power radar and other microwave systems possible.

In another type of electron tube, called the *klystron,* the velocity of the emitted electrons is varied. The electrons are allowed to accumulate in "bunches" as they travel along the length of the tube. Each "bunch" that arrives at the anode corresponds to a single cycle in a modulated current. Following the klystron and the magnetron in the 1930's, numerous other microwave oscillators and amplifiers have been developed. One such device, the *traveling-wave tube,* can amplify a wide range of microwave frequencies. It in turn has led to still more versatile electron tubes for this purpose.

Some electronic devices form and make use of a *beam* of electrons. Among them are the cathode-ray tube and phototube described below. The *cathode-ray tube* is familiar to us as the tube of a television receiver. In the tube, a beam of electrons—the "cathode rays"—strikes a spot on a screen that is coated with a fluorescent material, and the beam gives up its energy in the form of light. As the beam is shifted from one spot on the screen to another, it forms a definite pattern, the "picture" of the television receiver. The brightness of this pattern can be regulated by changes in the intensity of the beam. The cathode-ray tube is used not only in television but also as a means of studying various electric and electronic phenomena.

A few metals, such as cesium, emit electrons so readily that a small current can be obtained when these metals are struck by light. This phenomenon has led to the development of another class of electron tubes, known as *phototubes.* In these a specially prepared cathode emits electrons when exposed to light. The phototube is used in television, facsimile transmission, burglar alarms, and the sound system of talking pictures. It serves to open doors; count, sort, and inspect industrial materials; control machine operations; and prevent fires. It enables astronomers to measure with considerable accuracy the faint light of a distant star. These are only a few of the phototube's many uses.

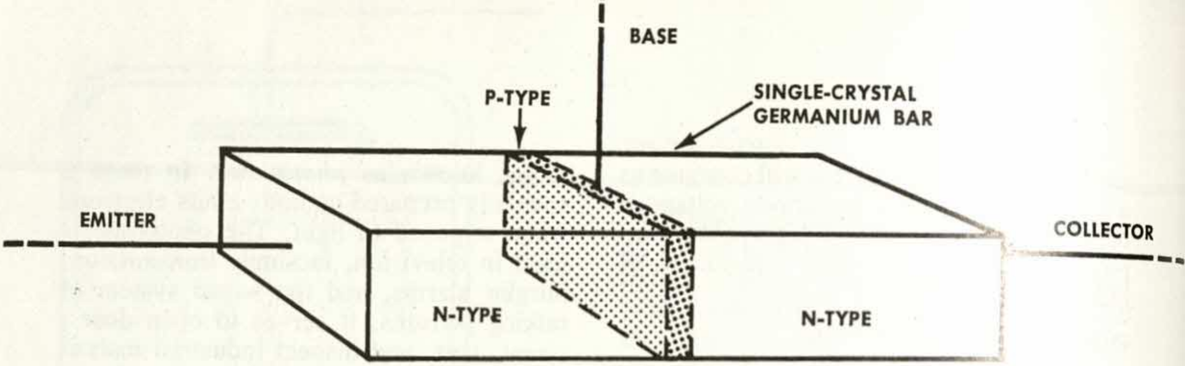
TRANSISTORS

Thus far we have been dealing with the flow of electrons in various kinds of electron tubes. They have served as a basic introduction to the science and technology of electronics. However, a major innovation in electronics took place in the late 1940's with the development of devices in which electrons flow through solids instead of vacuum or gas-filled tubes.

Solids now perform most of the functions of conventional electronic tubes. To understand this, we must consider the structure of solids and why some act as electrical insulators, others as conductors, and still others as both insulators and conductors. Those that act as both are called *semiconductors* or *transistors.*

The first transistor was called a *point-contact transistor.* It was basically a small wafer of germanium, onto one surface of which two pointed wire contacts were made, side by side and close together. On the opposite surface of the wafer, a third contact was made with a flat metal electrode. The resistance of one point contact was found to depend on the current passing through the other point. In other words, the resistance effect was transferable from one point to the other. From this came the name "transistor."

When an input signal was applied between one point contact, called the *emitter,* and the flat electrode, called the *base,* an enlarged replica of the signal was obtained between the other point contact and the base. As with a vacuum tube, the power for the amplification was drawn from a battery or other direct-current source.



Junction of a npn junction transistor. The base region controls the amount of current passing from the emitter to the collector.

JUNCTION TRANSISTORS

Soon afterward, another type of point-contact transistor was developed. In this new type, the contact points were pressed against opposite faces of a very thin piece of germanium, and the base contact was provided elsewhere. This transistor showed that the transistor effect took place through the body of the semiconductor rather than merely along the surface, as some investigators had thought. It led the way to another type of transistor that was not dependent on point contacts. This new type, called a *bipolar junction transistor,* has largely replaced the earlier types.

The bipolar junction transistor is essentially a single crystal of a refined semiconductor, usually germanium or silicon. This crystal contains minute quantities of impurity atoms of elements such as antimony, arsenic, indium, and gallium, which have been deliberately introduced into the crystal. In the crystal a thin base is sandwiched between larger regions—the *collector* and the emitter. An electrode is attached to each region.

In one type of junction transistor, the emitter and collector regions contain impurity atoms with more electrons than are needed to bond these impurity atoms into the crystal lattice of the semiconductor crystal. These excess electrons are free to drift about in the crystal. Since they carry a negative charge, the semiconductor in these regions is called *negative,* or *n-type.*

The base region contains impurity atoms lacking some of the electrons needed to make a complete bond in the lattice. The absence of an electron in a bond leaves a hole with a positive charge. A nearby bonding electron can jump into the hole, leaving another hole behind it. This other hole may capture another electron, and so on. The hole then appears to move in a direction opposite to the electron movement. The semiconductor in this area is called *positive,* or *p-type.*

The number of impurity atoms put into a typical semiconductor is extremely small —about one in 100 million. However, that is sufficient to provide enough excess electrons and holes to carry current.

The boundary between semiconductor areas that are predominantly p-type and n-type respectively is called a *p-n junction.* In an electrical circuit, a p-n junction will permit current to flow across it in one direction more readily than in the other direction. The junction transistor is actually two p-n junctions in series and can be either *npn*—that is, with a predominantly p-type area sandwiched between two predominantly n-type areas—or *pnp.*

A diagram of an npn junction transistor is shown on this page. The thin base region acts like a gate or grid of a vacuum tube in controlling the amount of electric current passing from the emitter to the collector. When a signal is applied between the emitter and the base, an enlarged replica of the signal is obtained between the base and the collector. Depending upon how the three are connected, various amounts of current, voltage, or power amplification can be obtained.

FIELD EFFECT

The *junction field-effect transistor* was developed in the late 1950's. A *chip* of n-type semiconductor forms the main body of the transistor. P-type areas called *gates* are on either side of the chip. A *channel* of n-type material is formed between the gates. The two gates are connected by electrical contacts made to the top and bottom parts of the channel. The bottom contact is the *source*. The top contact is called the *drain*. The current flows from the source to the drain through the n-channel, and then goes elsewhere through the circuit.

ADVANTAGES AND USES

There are other types of transistors and semiconductor devices, and their applications are very diverse.

The vacuum tube now has a very limited place in electronics. This is because the transistor has several inherent advantages over the vacuum tube. (1) For many uses, it is simpler and potentially lower in cost than equivalent vacuum tubes. (2) The transistor requires only a fraction of the power needed by a vacuum tube. (3) The transistor usually operates cold, thus eliminating the need for warm-up time. (4) The transistor can be made as small as a pinhead, permitting extreme miniaturization. (5) The transistor is extremely reliable when properly manufactured and operated within its design limits. It may have a trouble-free life for decades. (6) The transistor is remarkably resistant to shock and vibration.

One of the first commercial uses of the transistor was in hearing aids. Since its first use, it has made these devices far less bulky and more reliable than before. Transistors have also replaced the vacuum tube in telephone and telegraph equipment and in radio. Television sets are transistorized with the exception of the picture tube and possibly a few other components. Transistors serve in test equipment, automatic controls, signaling equipment, automobile ignition systems, and medical devices. They have revolutionized the construction of electronic computers, where great numbers of amplifying devices must be used together. In aircraft, radar, missile guidance, communications, artificial satellites, and spacecraft, their small size and weight and their minimal power requirements are a tremendous asset.

The growth of the electronics industry and the worldwide interest in electronics has been one of the most remarkable developments of the 20th century. From the vacuum tube of the 1930's to the transistors of the 1980's, few scientific advances have had as rapid an impact on society. The electronics industry in the United States, Japan, and Western Europe is a multibillion-dollar business.

The major thrust over the past several decades has been the production of miniature electronic circuits on very small semiconductor "chips," no larger than a postage stamp. These microchips contain as many transistors and other circuit elements as engineers can compact efficiently. They are so complex and powerful that they are doing more and more jobs once handled by complete electronic systems (see the article on Microprocessors).

By the late 1980's, experts expect that almost every office will be affected by the technological revolution brought about by the microchip. Electronic devices are replacing manual methods of filing, accounting, and transmitting business data. Computers and word processors are familiar items, even in the home. One can only imagine how these and future developments in electronics will reshape our lives.

John Bardeen, William Shockley, and Walter Brattain received the Nobel Prize in 1956 for their investigations leading to the invention of the transistor.

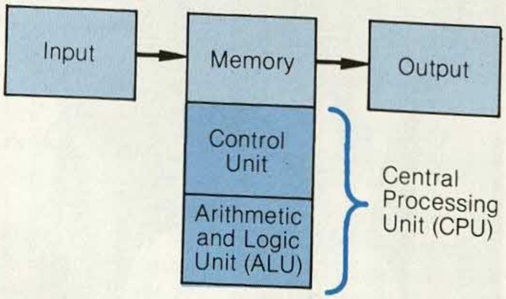
Jack Steinberg A.T. & T.

MICROPROCESSORS

What do home TV games, programmable microwave ovens, hand-held calculators, digital watches, a modern jet aircraft, and the car in your future have in common? The answer to this question is that each contains one or more microprocessors. Microprocessors, often called "computers on a chip," affect us in many different ways at home, at work, and at play.

The multibillion-dollar market for microprocessors has created an environment of high technology that now touches nearly every aspect of our lives. The development of microprocessors has, for example, revolutionized the computer industry. In 1947 a three-ton computer costing millions of dollars occupied a large room. Less than four decades later, a chip costing a few dollars and no larger than a fingernail could outperform its massive forerunner. In the field of education alone, the use of microcomputers in the classroom grew from 15,000 units in 1981 to more than 60,000 units in 1984.

Microprocessors are a result of the miniaturization of electronic parts and circuits. A microprocessor is an important part of a very small digital computer, called a microcomputer. All computers, regardless of their size, have the same five elements: input, memory, control, arithmetic and logic, and output. The figure shows the relationship between these elements. Data and instructions enter the computer through the input unit. They are stored in the memory as combinations of the binary digits, 1 and 0.


Input
Memory
Output
Control Unit
Arithmetic and Logic Unit (ALU)
Central Processing Unit (CPU)

Elements of a computer.

BITS AND BYTES

Binary digits are called *bits*. Groups of bits, called codes, are used to store combinations of characters, (letters, numbers, and special symbols) as data. Examples of binary-coded characters are: 11110001, an eight-bit code for the number 1, and 11000001, an eight-bit code for the letter A.

Any eight-bit-code, such as the ones above, is called a byte. The codes for instructions are also made up of bits and bytes. The sequence of instructions put into the computer to solve a problem is called a *program*.

MANAGING INFORMATION ELECTRONICALLY

The control unit of a computer acts much like an officer directing traffic. It manages the operations of all of the other units of the computer. The control unit interprets the instructions that make up the computer program. Then it causes them to be executed in a correct sequence.

The arithmetic and logic unit, called the ALU, performs the actual operations upon the data. The control unit and the arithmetic and logic unit together are called the central processing unit, or CPU. Thus, the CPU causes incoming data to be processed and converted into usable information. This information can be recorded or displayed on suitable output devices.

A *microprocessor* (often called a microprocessor unit, or MPU) is a CPU miniaturized to fit on a single silicon chip. Such a chip is no larger than one-half centimeter square. Microprocessors are the most difficult circuits to design. In fact, their design and layout can take many months. The tiny microprocessor is the product of a new technology called microelectronics.

Microelectronics is the ability to design and to fabricate large numbers of miniaturized circuit elements. Current microelectronic techniques place thousands of elements on a small silicon chip. These techniques also combine the chips into complex electronic circuits. These electronic circuits are called *integrated circuits,* or ICs. Because they are low-cost, reliable, and reproducible, ICs are used in digital computers in large quantities.

INTEGRATED CIRCUITS

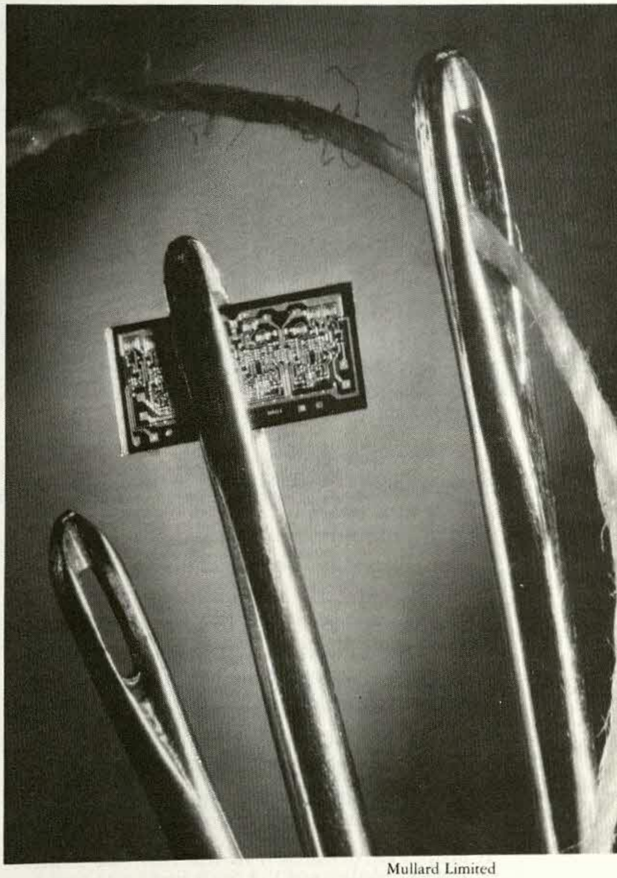
Prior to the development of the IC, electronic engineers used printed circuits—tiny electric circuits with all of their connections printed or etched on special insulated base materials. The printed circuit carries discrete components that are manufactured and applied to the circuit in separate processes. The IC has not only improved on the design of the printed circuit but has reduced its size considerably.

There are two kinds of integrated circuits—the *film type* and the *semiconductor type* (see the article "Introduction to Electronics").

Film-type integrated circuits. These types of circuits may be made of thick or thin film. Thick-film ICs are made by painting, plating, or pasting materials on a ceramic or plastic *wafer* or a semiconductor *chip*. The various bases are called *substrates*. The materials used to construct the integrated circuit are arranged in such a way as to carry out the functions of wire and other circuit components. Resistive paints, for instance, are used to provide the function of resistors. Conductive paints, on the other hand, are used to provide the functions of wires and capacitors. There are still some discrete components involved in the construction of the integrated circuit. Transistors, coils, diodes, and other components are later soldered onto the film on the wafer or chip.

In *thin-film integrated circuits,* the circuit is made by electrodepositing material onto the substrate. Some components, such as transistors and diodes, can be plated directly onto the circuit.

Semiconductor-type integrated circuits. The semiconductor integrated circuit greatly advanced the microminiaturization of circuits. The semiconductor integrated circuit areas and lines that function as wires and components. These circuit functions are found inside and outside the chip of semiconducting material. The regions can perform the functions of capacitors, resistors, transistors, and diodes.



Mullard Limited

Some integrated circuits are small enough to pass through the eye of a needle.

To make a semiconductor integrated circuit that performs the functions of a simple circuit containing a resistor, transistor, and diode, you start with a silicon chip that carries a positive charge—a *p-type* chip. Next, in a process known as *doping,* you add specific impurities to the chip so that you obtain positive, or *p,* regions and negative, or *n,* regions. A layer of silicon dioxide is placed over the *n* and *p* regions. This layer acts as an insulator. Openings in the layer are cut at specific points. Metal conductors are then placed on the top of the silicon dioxide layers and through the openings to provide connections with the inner regions.

MICROCOMPUTERS

A microprocessor becomes a microcomputer with the addition of a memory unit and input/output (I/O) circuits, called *ports*. The ports connect the microcomputer with input and output devices. The *data bus* is the electronic path that links the two parts of the microcomputer.

The memory unit contains two types of storage made of semiconductor materials: random access memory (RAM) and read-only memory (ROM). RAM is high-speed memory on which the computer system can both store (write) or access (read) information. Typically, RAM is used as main memory for storage of up to 64,000 bytes. The MPU registers also are RAM.

The capacity of a memory chip is measured in kilobytes (*K*), or units of 2^{10} (1,024) binary digits. The capacity of the chip has been increasing exponentially owing to new engineering achievements. In the mid 1980's, the United States and Japan competed to design and market a 64K dynamic RAM, which actually has a capacity of 65,536 bits. It is called "dynamic" because it stores information in the form of evanescent electric charges, which must be renewed periodically. Before the end of the 1980's, a 256K dynamic RAM is expected to be on the market.

ROM is memory that can only be read. It cannot be written on by the computer. ROM is useful for storing programs that should not be altered. For example, the instructions essential to the operation of the computer are stored in the ROM. So, too, are programs that translate human-readable instructions into the binary language of the computer. TV games, hand-held calculators, and other items also use ROMs.

Initially, microcomputers used two separate chips, one for the MPU and another for the I/O ports and memory. Currently, single-chip microcomputers are available. With the addition of actual I/O devices, such as keyboards, cathode-ray tube (CRT) displays, printers, and soft (floppy) magnetic-disk storage units, the microcomputer becomes a microcomputer system.

THE FUTURE: SMART MACHINES

Approximately 35 years ago, the transistor was developed as a replacement for the bulky, power-consuming vacuum tube. In the 1960's and 1970's, transistors were used in large quantities in digital computer design. Continual progress was made in reducing the size of integrated circuits. Microelectronics passed through three states of miniaturization: small-scale integration (SSI), medium-scale integration (MSI), and large-scale integration (LSI). The 1980's ushered in a fourth stage, very-large-scale integration (VLSI). VLSI increases greatly the number of logic circuits and bits of memory that can be placed on a single silicon chip.

Present LSI densities are less than 100,000 devices per chip. Soon VLSI densities of at least a million devices per chip are likely. This means that a million bits of memory could be stored on a single chip. For example, a chip could contain a microcomputer complete with complex logic circuits, 250,000 bits of memory, and other supporting electronics. At the same time, chips may be even smaller in size than at present and will cost less.

Ironically, just as ICs have revolutionized the computer industry, the computer is now the essential element in IC design. Once a design engineer establishes the basics, the computer takes over, stringing together previously developed elements for specific functions. Computers have become the tools for designing ICs, and we are only at the beginning. By the early 1990's, predict some experts, we will see on the order of 15 to 20 million devices on each chip.

We are entering an era that will be heavily influenced by the presence of smart machines—machines that contain one or more microprocessors. Smart machines will have increasing use in the home, in the office, and in the marketplace. Our lifestyles and our standards of living will perhaps be altered to an extent greater than we can now imagine.

In the brief period since its introduction, the personal computer has proved itself to be an important educational tool for people of all ages.

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PERSONAL COMPUTERS

by Gerald S. Axelrod

"When can I have my turn at the computer?" is the question anxiously asked of many modern parents concerning the personal computer, one of the newest, most exciting additions to the array of electronic devices usable in the home. The personal computer manipulates numbers rapidly and can store, sort, and retrieve enormous amounts of information. Whether performing as a budget balancer, math tutor, game player, or as a portal to almost limitless stores of data, it is fast becoming a familiar and tireless contributor in many households and small businesses.

Personal computers are becoming more popular as prices are lowered and operation becomes more simplified. Competition among manufacturers continues to encourage the evolution toward more powerful and more affordable personal computers.

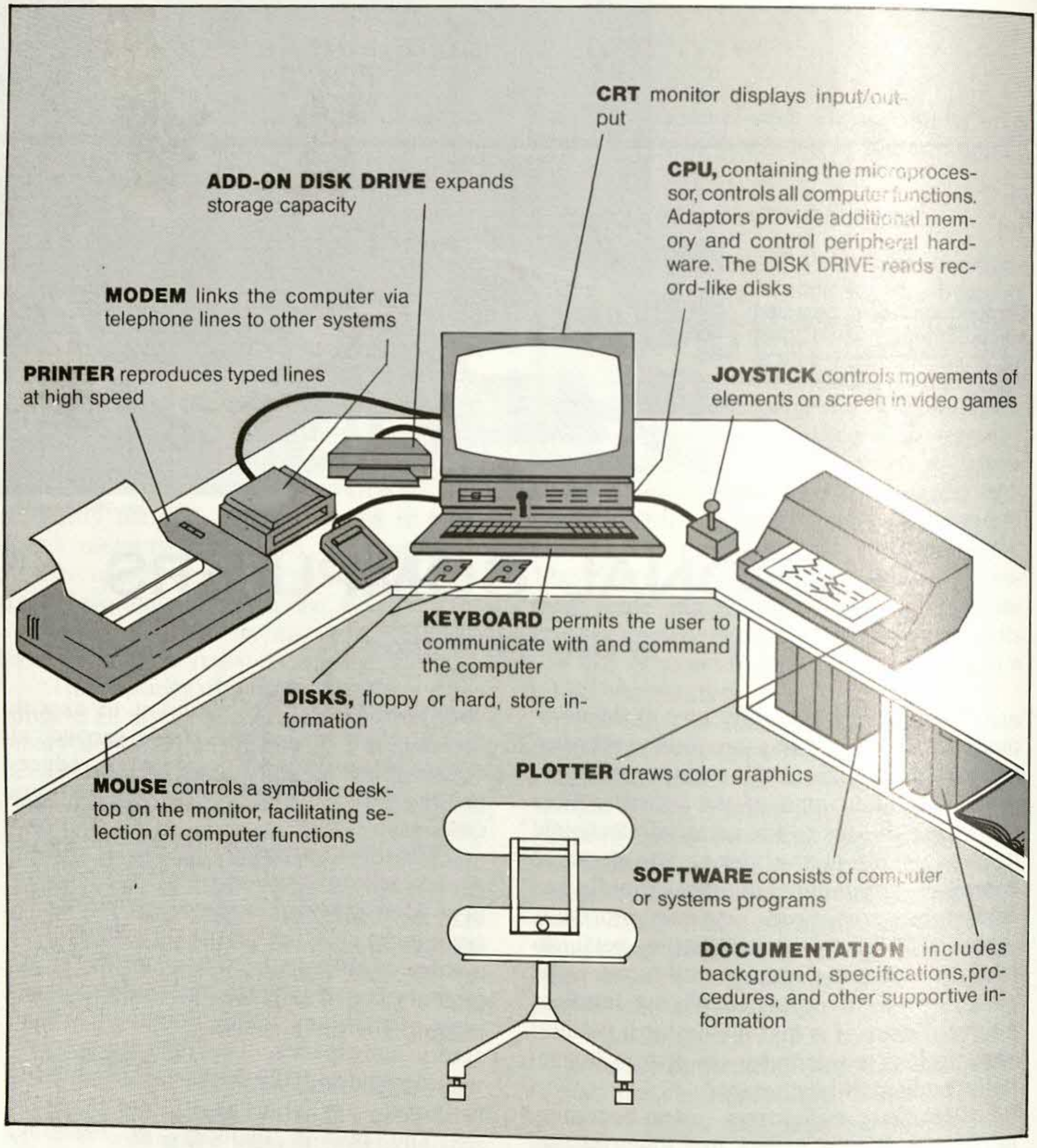
A TYPICAL SYSTEM

The heart of any computer is its *central processing unit* (CPU). In the personal computer the CPU is usually a group of silicon chips, or microprocessors, that together control and synchronize the various components of the computer as well as perform the arithmetic and logic functions of the system. The speed of the microprocessors within the CPU allows it to execute thousands of tasks in a single second, although all of its operations must be reduced to the simple level of combining zeros and ones.

Closely associated with the CPU is the computer's primary storage unit, or memory. Memory is measured in *bytes,* each containing eight *bits,* or binary digits, with a value of either 0 or 1. One *kilobyte* (K) of memory contains 1,024 bytes of storage. A page of this book holds about 4,160 characters and spaces. To store its contents would require 4,160 bytes (33,280 bits) of memory.

The built-in memory, or *read-only memory* (ROM), contains the operating instructions for the computer and usually the interpreter that translates readable instructions into the binary language of the computer. The second kind of storage in the memory unit, *random access memory* (RAM), is like the scratch pad for the computer, holding instructions for the task at hand. Unlike ROM, the RAM is lost whenever the power is turned off. It may be stored on tape or disk.

Many personal computers are based on microprocessors that can use only eight bits of data at a time and can access only 64K bytes of RAM easily. Inexpensive



CRT monitor displays input/output

CPU, containing the microprocessor, controls all computer functions. Adaptors provide additional memory and control peripheral hardware. The DISK DRIVE reads record-like disks

ADD-ON DISK DRIVE expands storage capacity

MODEM links the computer via telephone lines to other systems

PRINTER reproduces typed lines at high speed

JOYSTICK controls movements of elements on screen in video games

KEYBOARD permits the user to communicate with and command the computer

DISKS, floppy or hard, store information

PLOTTER draws color graphics

MOUSE controls a symbolic desktop on the monitor, facilitating selection of computer functions

SOFTWARE consists of computer or systems programs

DOCUMENTATION includes background, specifications, procedures, and other supportive information

The drawing shows some of the peripheral hardware that can be used to expand the effectiveness and versatility of the personal computer.

256K RAM chips have become available and, as computers are upgraded, may be the future standard for personal computers.

The CPU and memory are deaf and blind without *input/output* (I/O) *devices*. The simplest include a cathode ray tube (CRT) terminal, or monitor, a keyboard, joysticks to operate games, a printer, and a tape or disk recorder and playback device, or drive. I/O devices are also called *peripherals*.

POWERFUL PERIPHERALS

The *disk drive* is more versatile than the tape drive. It can access programs or data from any location on the storage disk using a read head similar to the arm on a phonograph. Mini–floppy disks, or diskettes, are low in cost and reliable. A standard 5¼-inch diskette can hold about 150K on a side. Less expensive 3½-inch and large-capacity 8-inch diskettes are also available. For more extensive storage tasks, a hard disk enclosed in a dust-free environment may hold from 5 to 20 megabytes (million bytes, or M).

A *modem* (modulator/demodulator) connects the computer to the outside world via telephone lines. It converts the electronic signals from the computer into tones that can be carried over telephone lines. The speed of data transfer, in bits per second, is referred to as the baud rate. Most home computers transfer at 300 baud, or almost 40 characters per second.

With a modem, connections can be made to computer networks offering a wide variety of services. These include access to databases, electronic mail service, electronic shopping, news and informational services, and computer games.

Databases may include library research services with comprehensive cataloging. A physician, for example, may locate all the most recent papers and abstracts on a disease and its treatment by accessing a medical database. Electronic mail service allows users to leave messages for one another. These are stored elctronically until they are accessed, and no printed copy may exist. Electronic shopping allows a bargain hunter to scan nationwide catalogs on the monitor at home and to charge purchases to a credit card number. In addition, the modem permits access to larger computers used for running complex programs.

To prepare permanent copies of whatever appears on the monitor, small *printers* are available for home use. Thermal printers burn letter-shaped dot patterns in special coated paper. Quality is poor, but the printers are inexpensive. Dot-matrix printers use a grid of small dots to create characters. Print quality may not be perfect, but dot-matrix printers are fast and can reproduce graphics. The slower daisy wheel printers, using a rotating wheel of type characters and a hammer mechanism, have multiple typefaces and excellent print quality.

Graphic tablets and *light pens* allow users to draw on the CRT screen without the need for sophisticated programming. To use the graphic tablet, one draws on a special pad with a stylus, and the corresponding design is created on the computer screen. It is saved in RAM for manipulation or later transfer to disk or plotter (which records graphics on paper) for permanent storage. The light pen is actually used on or near the surface of the CRT. Its position is detected by the CRT and relayed to the computer.

Voice recognizers are evolving rapidly. It is already possible to communicate with a computer without the aid of a keyboard or CRT. *Voice synthesizers,* simulating the human voice, are surprisingly effective, and *music synthesizers* allowing complex harmony and chord structure are available for some personal computers.

USES FOR PERSONAL COMPUTERS

Even the most sophisticated personal computers are helpless without intelligent users. Many owners can write programs, or software, in a simple computer language but rely on purchased programs to expand the range of computer uses.

Entertainment is a popular use of personal computers. Colorful high-resolution graphics and multivoiced sound and speech synthesizers have brought the quality and excitement of arcade games into the home. There are highly versatile entertainment programs, such as interactive novels and adventure games where user participation changes the outcome of the story.

Many software programs exist to simplify and abet personal finance and record keeping. These may be used to balance a checkbook, keep monthly and yearly family finances in order, and retain income tax or investment records. Larger record-keeping programs, called spreadsheets, are used by professionals and small businesses to display compilations of data and to make statistical projections.

EDUCATIONAL COMPUTING

Educational software can teach a variety of subjects from math tutorials to programming. Programs can teach by drill and practice or can involve the student with simulations of events ranging from chemical processes in primeval ecosystems to physical changes inside a nuclear reactor.

Drill and practice programs are used for reinforcement of previously acquired skills. A simple drill and practice program might involve random generation of math problems and giving the student sufficient tries to arrive at the solutions before revealing the correct answers. More complex programs can adjust the level of difficulty as the student progresses, keep records of performance, and provide a compilation of areas of weakness for teacher use.

Drill and practice can also be used to teach motor skills such as touch-typing. Sophisticated typing programs can keep track of areas of student weakness and emphasize these in later exercises. Motivational typing games, such as shooting down letter combinations, much like in an arcade game, can make learning fun.

Tutorial programs teach new skills. There are many programs that teach computer programming. Such instruction is easily translatable to a computer format. Tutorial programs that teach conversational language are also common and may be very successful when combined with the use of voice synthesizers. Subjects such as accounting, algebra, and physics have been adapted to the tutorial format.

Simulation, another type of educational program, allows users to input variables that will affect the outcome of a simulated event. Decisions determine the outcomes of events within parameters drawn from real data.

For example, a whale migrating along the Pacific coast from Canada to Mexico appears to make certain decisions as to feeding, swimming speed, responses to other creatures, and so on. A simulation of whale migration allows us to investigate whale behavior by "witnessing" the outcome of a variety of decisions confronting the whale: Not stopping to feed may result in weakness or death. Delaying too long en route may bring the whale to the breeding grounds too late to find a suitable mate.

Interactive video programs are a new and different format for educational computing. These involve connecting a videocassette or videodisc player with a personal computer. In some programs material is presented by means of a video lesson—as in educational TV—followed by a quiz. If any mistakes are made, the sections of the lesson that provide the correct answers are automatically replayed. The quiz is then reviewed until the acceptable level of competency is demonstrated. Corporate training departments have found this format very useful.

WORD PROCESSING

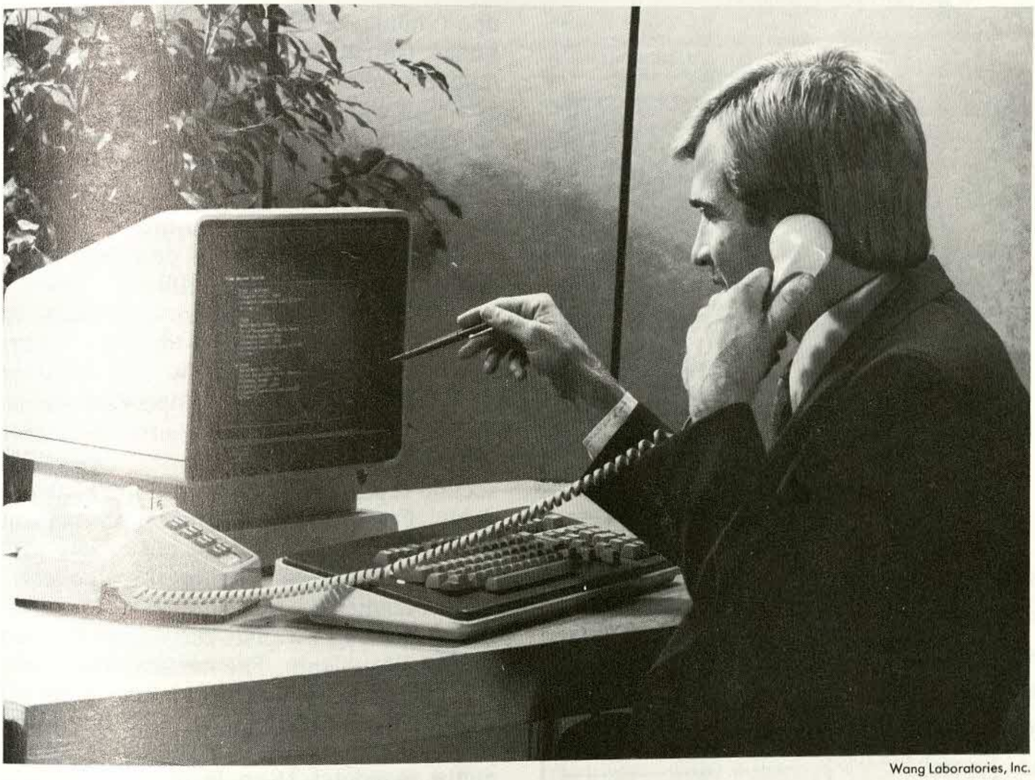
Word-processing programs can save a lot of time for people who have large amounts of typing to do. With a typewriter, one misplaced word might require retyping an entire page. In a long report, deleting one paragraph might affect several pages or more. With a word processor, the text being prepared is stored on a disk before it is printed. Changes are made on the CRT and in the RAM as the computer automatically reformats the corrected text. The result is printed out with letter quality.

Multiple originals adapted for specific purposes can be easily prepared from one basic letter. Much of the drudgery of routine office work can be minimized using word processing.

HOBBY USE

Hobbyists enjoy personal computers in a different way. Many are members of user groups that meet in person or via modem to exchange programs and ideas. Robots and robotic devices are available as hobby kits. Some dedicated computerists control their homes using a computer to regulate heating and cooling, lighting, appliances, and alarms. Advanced users can change the working of their computers by writing additional or new ROM.

The personal computer is an exciting device with growing significance. A powerful instrument of communication, calculation, and learning has been made available to great numbers of people. As personal computers expand in usability and application, they will play more and more important roles in our society as well as in our daily lives.



Wang Laboratories, Inc.

This state-of-the-art office workstation integrates word-processing and dictation, permitting a worker to dictate and edit voiced messages.

OFFICE AUTOMATION

by Benedict A. Leerburger

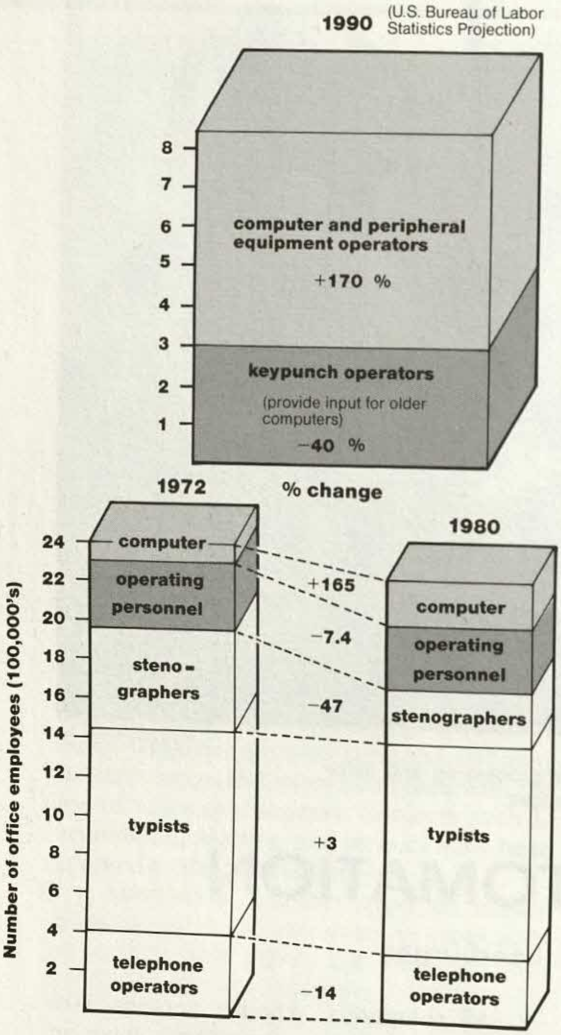
View any 1960's movie containing an office scene, and the props are similar: a few standardized office machines such as typewriter, dictaphone, adding machine, and telephone. The Hollywood film of the present and future, however, to be realistic must present a more automated office scene.

The computer has revolutionized office techniques in recent years and shows every sign of altering standard office procedures in the future. Such innovations as computer-generated business graphics, word processors, teleconferencing, electronic mail, and databases are all computer-controlled and have improved office efficiency in startling ways.

All computers, whether personal size or huge mainframe complexes, have in common the ability to analyze and compute, or to work with thousands of numbers per second, and the ability to store vast amounts of information, sort through it, and retrieve it on command. The 19th-century English mathematician Charles Babbage is probably the father of the modern computer. His plan for an "analytical engine" contained the basics of today's computer. It consisted of a "mill" that employed specific rules to manipulate data, a memory for storing information, a unit that carried out the user's instructions, and a facility for placing information into the machine and retrieving it.

OFFICE AUTOMATION

Shifting employment reflects the changing nature of office work and an increasing concern with office productivity.



All computers, like Babbage's early one, can be programmed. That is, an individual can present the computer with a set of organized commands so that the machine can complete a specific job, such as identifying grammatical errors in a text or managing a payroll.

Capacity is perhaps what distinguishes the small personal computer from the huge corporate one. But because components are so similar, distinctions are blurred as to what constitutes a personal computer and what constitutes an office one. Many small businesses, for example, successfully rely upon home computers to organize customer names, addresses, and telephone numbers, or to prepare monthly invoices.

One estimate for the number of personal computers in use by the year 2000 is 80 million. Certainly many of these will be in offices. Numerous office workers now use these computers at home. The office away from the office saves company space and employee commuting time.

In recent years, offices have come to rely upon the services of computers in varied and unusual ways. In the office at southern California's Antelope Valley High School, for instance, every afternoon after school, the school's computer phones 30-second reports to the parents of truant students. For businesses, computers present lists to salespeople of all customers in a certain zip code or telephone area code.

In medicine, computers assist in making diagnoses as well as keeping records on individual patients. The medical data bank, CADUCEUS, stores 4,000 symptoms of more than 500 diseases. It can distinguish patterns in symptoms that patients report, and then suggest diagnoses. Such computerized activity in a hospital office can save valuable doctor and nurse time. Computerized filing systems have simplified office procedures, as have automatic bank teller machines. Robots have so far been used largely in factories, but perhaps an office worker of the future will be a skilled robot.

TELECONFERENCING

A major advancement for the automated office has been teleconferencing. Through audio and visual wall screens, this phenomenon allows participants from all over the country or the world to attend meetings without traveling, thus eliminating travel time while involving people as necessary to solve a problem. Cost savings are also important. Computerized visual and audio segments are essential to these meetings. People can confer with each other as they see members of a group on video screens. In addition, with split-second timing, they can transmit written and visual materials or any data needed for the specific conference.

Utilizing satellites, these conferences can be arranged with either full movement or what is called "freeze-frame"—video pictures that change only intermittently and are less costly than the full-motion variety. One venture planned for the mid-1980's will provide relay satellites and earth stations, with clients using their own office terminal equipment for teleconferencing. Another planned satellite-based system requires customers to lease satellite space. With an earth station in each of 200 metropolitan areas, it will allow high-speed document and data transmission along with teleconferencing.

DATABASES

Clearly an essential factor in teleconferencing is the sharing of timely and complex data, and a major requirement for the automated office is its database, a computer file of information on individual subjects or a combination of subjects. More than 1,200 databases were available to computer users in 1983, with more appearing monthly.

To take advantage of databases, office personnel need a computer and a modem, a device that converts computer signals for telephone transmission. In the future, satellites will link computers together with high-speed service, avoiding the need for conventional telephone service. Voices will be converted to computer-readable electronic signals (digitized) before being transmitted at phenomenal speeds and then reassembled at the receiving end.

What kinds of databases are available? Some are very specific—such as meteorological information—and some are much more general, such as one that maintains financial reports on leading U.S. companies. Some are simply files containing news stories or information printed in various publications. Statistical information is available on varied aspects of business and finance, both in the United States and abroad. One can tap a law database for legal precedents or find information about the workings of Congress, all in seconds.

During teleconferencing, participants can at the same time call for information from a database and also transmit their own statistics for comparative analysis. Some data banks allow participants to submit models for analysis. For instance, if participants in a conference are considering the pros and cons of building a new plant or adding to an existing facility, the data bank can not only provide statistics about such activities but can also enable the participants to weigh alternatives by examining mathematical simulations.

Another major type of database contains bibliographic data. The DIALOG system serves thousands of customers in dozens of countries, supplying them with bibliographic information in science, engineering, and business. Databases have been created to provide essential information for market-research companies, including econometric and financial forecasting. At least one New York City–based advertising agency has a room equipped with computer terminals that have access to some 200 databases, so that sophisticated information is available for any sort of conference. The agency can track how client companies perform within their industries or forecast individual product demand.

ELECTRONIC MAIL

A major revolution for the automated office is electronic mail. The familiar postal system requires that messages written on paper be transmitted physically from writer to receiver. With electronic mail, messages are changed into electronic signals, transmitted anywhere in the world, and then changed back into the original written form, all in several seconds or minutes at most. A 64-page document can be transmitted from California to West Germany in eight minutes.

Electronic mail is still expensive, for it must compete for transmission space on satellite, telephone, and cable links with television, voice, and computer-data telecommunications. But plans for additional satellite communication should assist in the spread of electronic mail.

Sending a single document to a single individual is a major use of electronic mail.

This version of the electronic desk provides access to an array of files and subsystems. It also permits reproduction of the images that have been created on the display screen.

Xerox

Through the use of multiple video screens in company offices, a single document can also be transmitted to hundreds of people in perhaps dozens of branch offices at the same time. Thus, electronic mail, along with databases, can be an important asset in teleconferencing. It may also reduce telephone activity and the volume of interoffice memos.

Electronic mail works through the office computer. A "send" key on a processor terminal may send the letter–in digital form–to people at other divisions. The computerized equivalent of the office telephone switchboard, called a private automatic branch exchange (PABX), may ensure that the letter is delivered to the proper location. Hundreds of PABXs have been installed all over the world in companies requiring electronic mail. A second method of transmission has been developed that requires a passive coaxial cable connecting electronic office equipment. Such systems throughout the country will then have individual digital addresses.

Another form of electronic mail employs an electronic "mailbox" attached to a telephone. Messages are stored and delivered to a recipient, in text form, eliminating wasted time on the telephone. Such "mailed" electronic messages are of great value, since in many offices three out of every four telephone calls may go uncompleted on the first attempt. With electronic mail, two-way conversation is not essential.

WORD PROCESSING AND COMPUTERS

Important in itself but essential to electronic mail is word processing, helping to make an office part of a business network. A word processor is a microcomputer with a keyboard and a telescreen. An entire page of a letter can be displayed on the screen, and corrections can be incorporated into it without retyping the entire letter.

Word processors in an office can be connected, so that if, for example, an executive is writing a letter or memo or lengthy report and wishes the comments of others, all involved can view the document on their individual screens. Changes can be incorporated into a single letter from various word-processing computers. With a word processor, a writer can shift paragraph structure, insert or delete sentences, and correct grammar and spelling. The writer can also evaluate comments that have been sent from other contributors and stored separately.

Office word processors are also being used to develop spreadsheets. These are budgets, financial analyses, and statistical data. Here again, an individual composing a spreadsheet could receive assistance from other employees through their own word processors. These cooperatively constructed and evaluated spreadsheets can be distributed to branch offices via electronic mail.

The word processor can assist with simple letters or with lengthy contracts of complex legal documents. One can write, make changes, and print with a word processor. If linked to an electronic mail system, the finished product can be transmitted to terminals anywhere in the world. An advantage of the word processor is the confidence the machine's text-editing capabilities seem to instill in its users. Additionally, instead of waiting days for a response to a business letter, the answer may be received almost immediately with communicating word processors.

THE ELECTRONIC DESK

Many of the functions performed by the systems described can be integrated more fully in the office system referred to as the "electronic desk." This personal work station includes a large monitor screen, a keyboard, and a device for positioning a pointer on the screen. There may also be such supporting equipment as a communications connection linking the desk to the entire office system. A printer, specialized files, and storage units enhance the station's capabilities.

The system can serve the professional or the general office worker, going beyond the already standard word-processing or text-editing functions by allowing access to central files, remote files, other work stations, and a network of subsystems.

By moving the pointer on the monitor, the worker can select and examine incoming messages or reports on the screen, review and update files, prepare notes or entire documents complete with charts and diagrams, and even dispose of unwanted material in an electronic "wastebasket." Other workers can be involved to assist at any point, and finished work can be automatically stored or distributed instantly.

PROBLEMS OF AUTOMATION

The automated office clearly has advantages in terms of efficiency, but disadvantages exist as well. Often office personnel are resistant to new equipment, particularly if it poses the threat of changing jobs. Sometimes office management itself fails to understand the new equipment and may be suspicious.

Another problem concerns excessive automation. Time saving and increased efficiency may result in the loss of interpersonal relationships, trading of ideas, and creativity. Employees using personal computers at home rather than in the office can feel isolated.

A particularly irksome development with computers has been the problem of evaluating and selecting from among the vast array of machines and software, or programs, available. Equipment may prove unsuited to its intended use. Some programs are not checked carefully and allow users to make mistakes. Sometimes the program is difficult to use, so that using a manual system might have been vastly easier. Office workers also complain about programs not being interchangeable for varied machines. Clearly, room for improvement exists in the automated office.

A serious problem for automated offices is that of potential unemployment. One study suggests that in the major industrialized nations, four of every 10 office jobs could be standardized and 25 to 30 percent could be automated. A more optimistic view is that computer technology creates even more jobs than it destroys. The controversy will continue for some time.

Technology in the office has its critics, but it also seems to have many enthusiasts. A key factor in the future of automated offices may be management's acceptance of automation and its willingness to try new and complex machines. The ability of managers to make decisions at a rate proportionate to that of the computer may be crucial. With more and better information at his or her fingertips—accessible at the touch of a button—a manager will no longer be able to delay making a decision for want of more information. The manager who can adjust to this "real-time" environment will survive; others will have problems.

THE PHOTOELECTRIC CELL

A Versatile Servant of Mankind

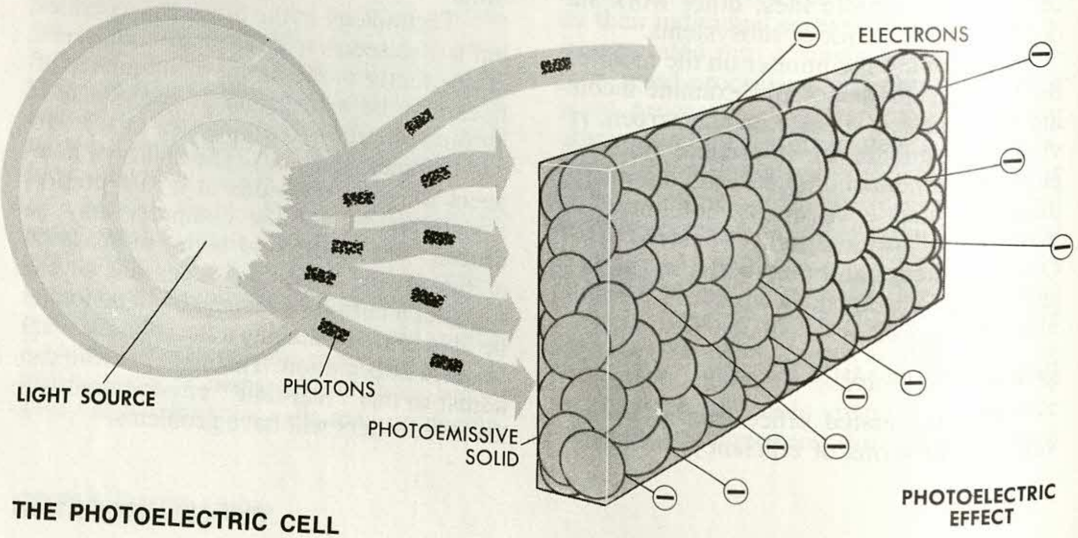
Since light is a form of energy, it is not surprising that scientists have transformed it into electricity, which is another form of energy. This is brought about by the *photoelectric cell,* popularly called the "electric eye." It may be defined as a device for making use of electrical phenomena brought about by light radiation, or in some cases by invisible ultraviolet radiation. The photoelectric cell has made television and talking pictures possible. It has been used to measure light, to open doors without the agency of a human hand, to inspect manufactured articles, and so on.

The principles underlying the operation of the photoelectric cell have been known to scientists for many years. The French physicist Alexandre-Edmond Becquerel was probably the first to note that the presence or absence of light produced an electrical effect. He had been experimenting in 1839 with glass-enclosed *primary batteries,* or those that have electrodes immersed in liquid. He noticed that the voltage of his batteries increased as the light falling upon them increased in intensity, and that green light provided the highest voltage. Becquerel also made the important observation that the increase in voltage was proportional to the intensity of the light falling on the batteries. For a long time, the phenomenon discovered by Becquerel remained a scientific curiosity.

Following a somewhat different approach, Willoughby Smith discovered in 1873 that the resistance offered to the flow of an electric current by the chemical element selenium varied according to the intensity of the light falling upon it. His discovery led to a long series of investigations of selenium and other metals that were affected in the same way. This brought about the development of the *photoconductive cell,* described later in this article.

In 1888, Wilhelm Hallwachs, a German physicist, discovered a fundamental *photoelectric effect.* He charged a polished zinc sphere with negative electricity and subjected it to ultraviolet radiation. The zinc ball soon lost its negative charge. The loss did not take place when glass was placed between the ultraviolet radiation and the zinc ball. There was also no loss of electrical charge when the zinc was positively charged. Hallwachs correctly concluded from these results that when ultraviolet light fell upon the zinc ball, the latter

A photoelectric effect, or photoemission. The photons of a light source strike a photoemissive solid and impart energy to some of its electrons. The energy may lift the electrons through the solid and off its surface.



lost "negative electricity." This phenomenon is known as the *Hallwachs effect*. The Russian physicist Aleksandr Stoleto made a further advance by collecting the electricity lost by the zinc ball.

In the years that followed, the German physicists Julius Elster and Hans Geitel constructed cells that made use of the metals sodium and potassium and other alkali metals. They showed that these metals were sensitive to visible light as well as to ultraviolet. These cells of Elster and Geitel were the direct ancestors of the *photoemissive type* of photoelectric cell.

Another great step forward was taken when the German physicist Philipp Eduard Lenard and the British physicist J. J. Thomson proved that the loss of "negative electricity" observed by Hallwachs was due to the emission of electrons by the illuminated body. In other words the carrier of the photoelectric current was the electron.

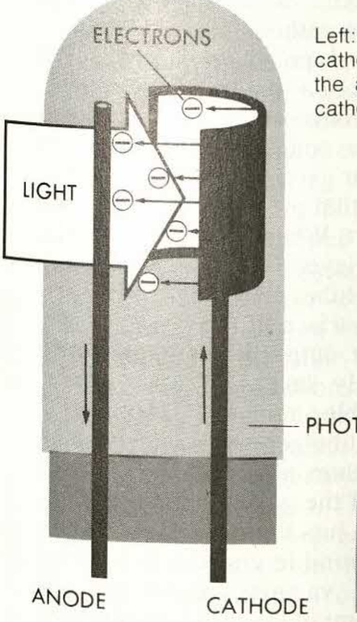
THE PHOTOELECTRIC EFFECT

It was not until the early 1900s that some understanding was obtained of why light may stimulate an electric current in some materials. The theories of German physicist Max Planck and German-American physicist Albert Einstein and later work by other investigators have given us the following picture of the photoelectric phenomenon—in this case, *photoemission*, or the discharge of electrons into space from a mass of matter under the influence of light.

In this situation, a beam of light is thought to consist of a wavelike motion of small bundles or packets of energy known as *quanta* or *photons*. When a photon of given energy strikes the surface of, say, a photoemissive solid, it imparts its energy to an electron, which is part of the substance of the solid (along with many other electrons). This burst of energy may be sufficient to lift the electron through the solid and off its surface into the surrounding space or medium. If enough photons can hit enough electrons with enough energy, a flow of electrons from the surface of the solid is initiated. These electrons can be attracted by a positively charged electrode, called a *collector*, so that an electric current in a circuit is set up.

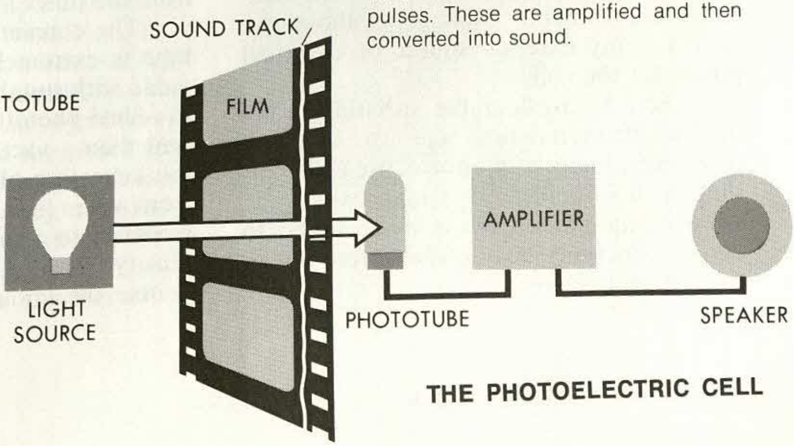
It has been found that the more intense the light, the greater the quantity of electrons released from a body's surface, up to a certain limit. But this occurs only with light of a certain range in frequencies or

PHOTOEMISSIVE CELL



Left: a photoemissive cell. When light strikes the electron-emitting substance on the cathode of the cell, electrons are emitted. Negatively charged, they are attracted to the anode, which is positive, and they continue around the circuit back to the cathode.

Below: applying the photoemissive effect to a movie sound track. Variations in sound had been previously recorded on the film, in terms of lighter or darker areas or of varying width. When the film is run off, as here, a phototube converts variations in the film into varying electric pulses. These are amplified and then converted into sound.



wavelengths. Light of low frequency, which has corresponding low energy, very seldom causes photoemission in most materials. This is the case with the red and infrared portions of the spectrum. (The metal cesium, however, responds to red light.) With light of high frequency, with corresponding high energy, photoemission takes place even if the light is dim, although the resulting current is very weak. This is particularly true of the green, blue, violet, and ultraviolet wavelengths, to which many substances react photoelectrically.

Substances that are capable of photoemission show surprisingly similar properties in this respect. They differ primarily in their *photoelectric threshold*—the frequency of light at which they begin to emit electrons. The electrons that are emitted under the impact of photons are often called *photoelectrons*, although they do not differ at all in their properties from electrons that are released by other means. In most cases, photoelectrons come from the outermost shells of the atoms involved. Many individuals played important parts in the development of photoelectric theory and devices. Lack of space makes it impossible to mention them here.

TYPES OF PHOTOELECTRIC CELLS

There are three principal types of photoelectric cells.

(1) *Phototubes*, or *photoemissive cells*, in which electrons are emitted by one of the electrodes in a tube when the cell is exposed to light radiation.

(2) *Photoconductive cells*, in which light causes a change in resistance to the passage of electric current.

(3) *Photovoltaic cells*, or *phototrons*, in which the action of light produces an electromotive force, or voltage, without the need for any external source of electrical power for the cell.

There is considerable variation in the design, characteristics, and use of these three main kinds of photoelectric cells. Although their applications may overlap in various situations, each is more suited to certain functions, as we shall bring out in the following pages.

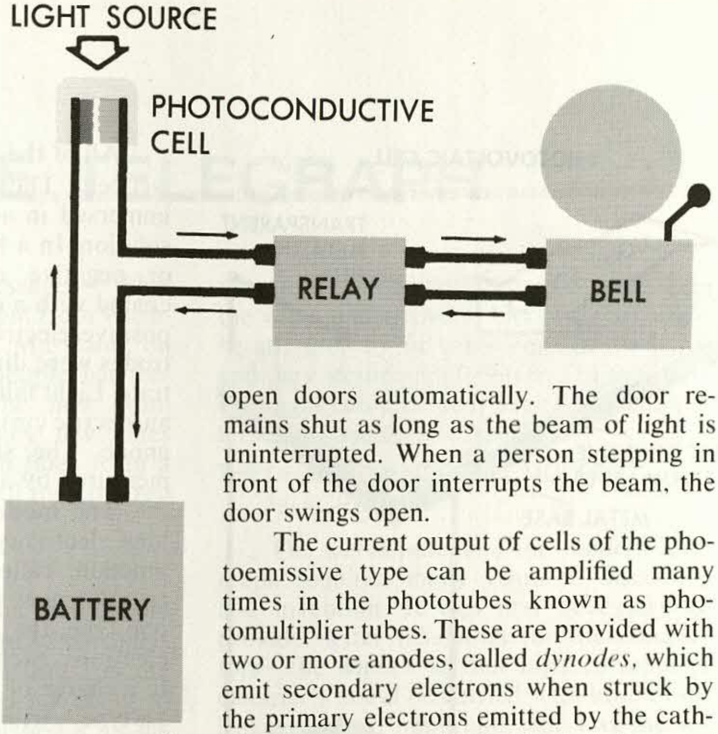
PHOTOTUBES

One type of phototube consists of a glass tube, either highly evacuated (that is, with a high vacuum) or else filled with some inert gas, such as argon, at low pressure. The electron-emitting substance, generally a compound of cesium or potassium, is deposited in a thin layer on a half-cylinder of silver or other metal within the tube. The coating represents the cathode, or negative electrode, of the cell. A connection is made between the cathode and one of the cell terminals. As light falls upon the coating—the cathode—it emits electrons.

The cell also contains an anode, or positive electrode, which consists of a wire extending along the axis of the cylinder. It is maintained at a positive potential with respect to the cathode by means of an external battery. The negatively charged electrons emitted by the cathode are attracted to the anode and continue around the battery circuit back to the cathode. Hence the phototube functions as an electric valve. It causes the current output to fluctuate according to the amount of light falling upon it. If the light beam is shut off altogether, the circuit is broken. In this case, the phototube represents an open switch in the circuit. The "switch" is closed when light again falls on the cathode.

In another type of phototube, the cathode consists of a semitransparent layer of the photoemissive substance applied to the envelope, or window, of the tube. A part of the layer is deposited on another layer of a metal that provides the necessary electrical contact. When light falls upon the surface of the layer in contact with the envelope of the tube, electrons are emitted from the inner surface of the layer.

The current output of a photoelectric tube is extremely small. Hence it is provided with suitable amplifiers and relays. A gas-filled phototube generates a larger current than a vacuum phototube because of the ionization of the gas by the photoelectrons when light hits the tube. However, it is slower to respond to changes in light intensity than a vacuum phototube. Of course, the amount of electrons produced is



A battery-operated photoelectric smoke detector. This device, which can be mounted on a wall or ceiling, is open on all four sides. When the detector "sees" smoke—that is, when the light entering it is even slightly obscured—it triggers an alarm.

not simply proportional to the amount of light entering the gas tube. Despite its lesser electrical output, the vacuum phototube must be used where quick response to small light fluctuations is necessary, as in many kinds of scientific instruments.

Phototubes have a great variety of applications. They serve as sensing elements in detecting and measuring light and other forms of radiation. They are used in light-controlled relay circuits. In these, variations in the intensity of light falling on the cathode brings about current variations.

The phototube plays an important part in sound movies. Variations in sound are recorded in terms of darker or lighter areas in the film or of varying width of the exposed areas. When the film is run off in a movie house, a phototube converts variations in the film into varying electric pulses. Amplified, they are converted into sound. The phototube plays an important role in television and in facsimile transmission.

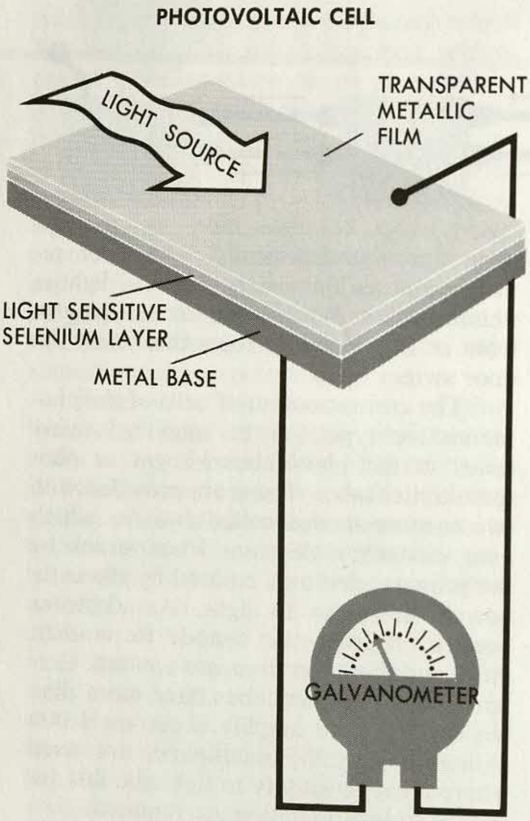
In certain applications, a beam of light is kept focused upon a phototube. Various devices are actuated when an object comes between the light beam and the phototube, thus cutting off the light. This effect is used as a safety feature, preventing a machine such as a press or cutting device from working when the operator comes dangerously close to it. It also serves to open doors automatically. The door remains shut as long as the beam of light is uninterrupted. When a person stepping in front of the door interrupts the beam, the door swings open.

The current output of cells of the photoemissive type can be amplified many times in the phototubes known as photomultiplier tubes. These are provided with two or more anodes, called *dynodes*, which emit secondary electrons when struck by the primary electrons emitted by the cathode in response to light. As electrons bounce off from one dynode to another, more and more electrons are emitted. Certain photomultiplier tubes have more than ten dynodes and amplify a current 1,000 million times. Photomultipliers are used where great sensitivity to light and fast response to light radiation are required.

PHOTOCONDUCTIVE CELLS

The *photoconductive cell* depends for its action upon the fact that the electrical resistance of certain substances varies with the intensity of the light that strikes them. Resistance usually drops as light intensity rises. A great many different substances display this property, including selenium, boron, germanium, silicon, and various compounds. In a photoconductive cell, a thin metal film is deposited on an insulator plate. The film is divided into strips with a thin dividing line between them. Alternate strips are connected. A thin layer of the photoconductive substance is deposited over the metal film. It forms a bridge across the dividing line between the strips. The assembly is enclosed in an evacuated glass tube, and the connections are brought out to terminal prongs attached to the base.

Photoconductive cells play an important part in television. They are used in photographic exposure meters when more



When light photons strike the boundary between two types of material in a photovoltaic cell, the result is an electric current. The strength of the current is measured by a galvanometer, thus indicating the intensity of the light.

sensitivity or power is required. They are used with batteries. The photoconductive cells are made of cadmium sulfide or cadmium selenide. Photoconductive cells are also employed in high-speed recording spectroscopy and in the detection of infrared radiation.

PHOTOVOLTAIC CELLS

Both photoemissive and photoconductive cells require an external source of voltage before any current flow can take place. This is not a requirement in the *photovoltaic*, or *phototronic*, type of cell, because an electromotive force is generated within the cell itself when it is exposed to light. This force is used in a variety of different ways, as we shall see.

All of the early cells of this type were wet cells. They consisted of two electrodes immersed in an *electrolyte*, or conducting solution. In a typical wet cell, the cathode, or negative electrode, was of copper, coated with a copper oxide. The anode, or positive electrode, was of lead. Both electrodes were dipped in a solution of lead nitrate. Light falling on the cathode produced an electric current between the cathode and anode. The strength of the current was measured by a galvanometer.

The modern photovoltaic cell generates electricity when light falls upon the junction, called a barrier layer, between two different types of semiconductors. In one type, the *n-type*, conduction is due to electrons, each of which represents a negative charge of electricity—hence the name "n-type" (n = "negative"). In the other type of semiconductor, the *p-type*, conduction is caused by so-called *holes*, or gaps, in the crystalline structure of the material. Each hole, in the absence of a negatively charged electron, is therefore considered to represent a positive charge—hence the name "p-type" (p = "positive"). Electrons and holes are considered to move or flow in the electric currents set up under the action of light. The *solar cell* is a photovoltaic cell.

The photovoltaic cell has been used extensively to detect and measure the intensity of light in photographic exposure meters. It also serves in the relay systems used in automation. It is also finding more and more extensive use in the form of solar batteries, each made up of thousands of solar cells. In the earlier stage of their development, solar batteries were used on a small scale to provide power for telephone amplifiers or repeaters. They have, however, proved to be indispensable in the space program. To name but a few of the spacecraft in which solar batteries have been installed, they are the *Tiros* weather satellites; the *Communication Technology Satellites* (CTS); the *Viking* craft used to study Mars; and the *Helios* solar observation crafts. Solar batteries have been used to charge nickel-cadmium batteries, which in turn provide power for the electronic circuits of the space vehicles.

THE TELEGRAPH

The first telegraph message—"What hath God wrought!"—was sent from Washington, D.C., to Baltimore, Maryland, on May 24, 1844. By 1848, people had become enthusiastic about the new communication device, and many new lines were built. Today, telegraph lines form a network extending through all the civilized lands of the world.

HOW IT BEGAN

Although the fact that electricity could be transmitted through a wire of considerable length had been demonstrated in the mid-eighteenth century, it did not occur to people that this finding furnished a means for the rapid transmission of signals. The earliest suggestion that electricity could be used in this way appeared in an anonymous letter to *The Scot's Magazine* in 1753. It is thought to have been written by a Scots physician, Charles Morrison.

In Morrison's method, as in other early methods, there were as many wires as there were letters to be transmitted. By charging the wires successively, bits of paper could be attracted to the other ends of the wires and they would signify letters. In this way, messages could be sent over a few kilometers at a considerable speed.

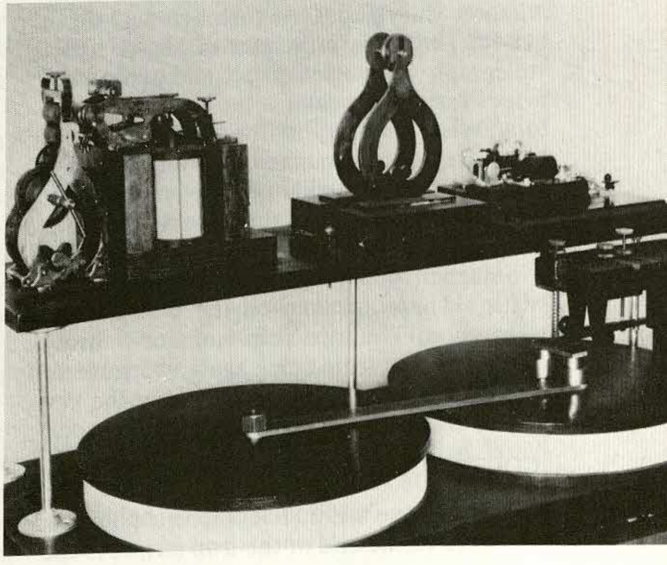
THE DEVELOPMENT OF THE MODERN TELEGRAPH

The development of the modern telegraph required many years of discovery and invention. It was first necessary to provide better insulators for the conductors—the wires—so that high currents of electricity could be carried with little or no leakage. More important still was the invention of a source of electricity that would send a steady current through the wires.

In the early part of the nineteenth century a number of inventors suggested the use of electric telegraphic systems that required only two connecting wires. This was an improvement over the old system.

Left: Samuel F.B. Morse, inventor of the telegraph. Right: replica of Morse's first telegraph of 1844. This instrument weighed about 80 kilograms. The modern telegraph relay weighs about one-half kilogram.

Western Union



The Danish physicist Hans Oersted's discovery of electromagnetism in 1820 was a culminating episode in the development of the electric telegraph. It was well known that varying impulses could be sent over a wire for a considerable distance, but no satisfactory way had been found to recognize the pulses at the receiving end of the wire.

Oersted discovered that an electric current flowing through a wire set up a magnetic field that would deflect a needle placed near the wire. The needle would align itself with the field. Andre-Marie Ampere, the French mathematician and physicist, suggested that the deflection of a magnetic needle should be used for the reception of electric signals. However, a practical needle telegraph system was not devised until 1837, by the British physicists Wheatstone and Cook.

MORSE'S TELEGRAPH

It would appear that the invention of the modern telegraph by Samuel F.B. Morse in 1837 resulted, in part at least, from a chance conversation between Morse and Dr. Charles T. Jackson aboard ship on a voyage in 1832.

Morse succeeded in constructing an electric telegraph that was better than any other devised up to that time. His first telegraph line was constructed under an appropriation of the U.S. Congress between Baltimore, Maryland, and Washington, D.C., in 1844. The basic principles of Morse's first telegraph were used in all telegraphic devices for many years.

When the key at the sending station was pressed down, the battery sent a current through the coils of an electromagnet at the receiving end of the telegraph. A strip of iron, originally held away from the electromagnet by a spring, was pulled against it with a sharp click when the current was turned on. The iron strip was drawn away from the electromagnet again, because of the action of the spring, whenever the key at the transmitting end was released.

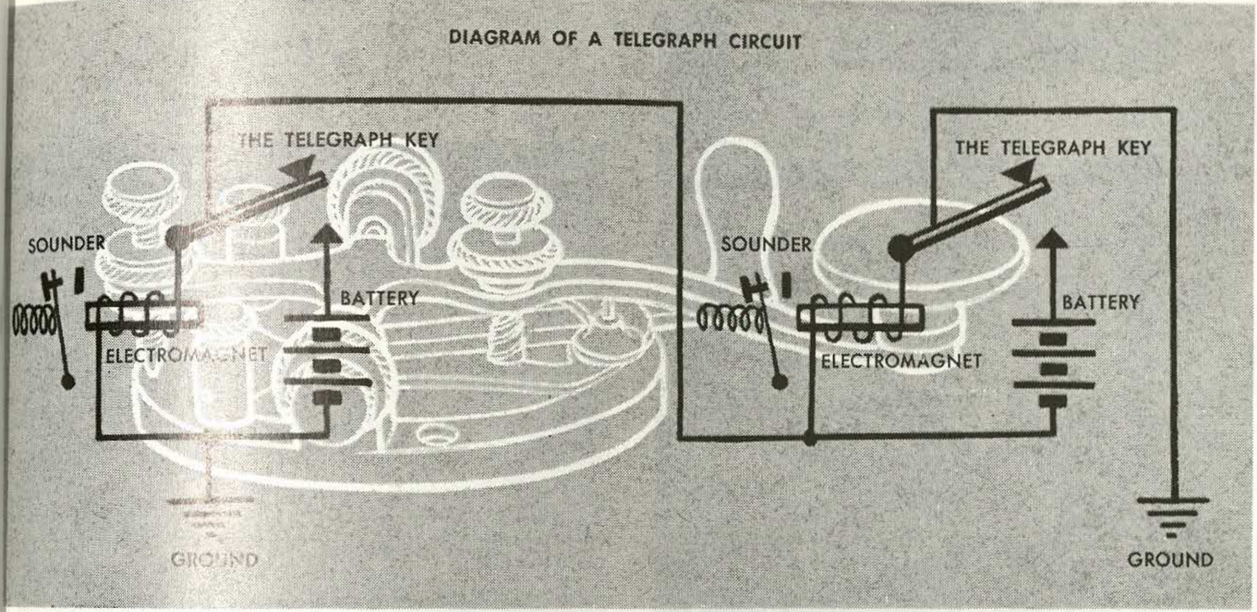
CODED SIGNALS

In Morse's first telegraph, a pen was attached to the end of the iron strip. As the strip moved to and from the electromagnet, the pen alternately made contact with a moving ribbon of paper and broke off contact. The result was a series of straight lines on the paper. Their length was determined by the length of time that the transmitting key was held down. Short lines represented dots and longer lines dashes, forming the *Morse code.*

Later, operators became so expert in receiving messages by sound that the printing method was abandoned. The receiving device was then used as a sounder. The dots and dashes of the Morse code were retained. This code is still in use, though to a limited extent, in the United States and Canada. A rather similar code, called the *Continental code*, is used in other countries for hand-operated devices, as well as for ocean-cable and radio telegraphy.

In his early machines, Morse noted that the current was much weaker at the receiving end than at the sending end, because of current leakage and the resistance of the wire. To overcome this serious difficulty, the inventor set *relays*, or repeaters, in the telegraph line at intervals. A relay consisted of an electromagnet which, as it attracted a strip of iron, connected a fresh battery with the next section of the line. Messages could now be sent with no appreciable loss in current strength.

Hand-operated devices, using transmitting keys and sounders and sending out their messages in code, have been gradually replaced by automatic equipment. They are still found in limited numbers at some railroad telegraph offices. Manual methods of operation require that the person transmitting read the message and actuate a telegraph key to convert each letter into a code group of short and long pulses, or dots and dashes. The receiving operator must listen to the code groups, translate them into letters and typewrite the letters onto the message blank to be delivered. Errors are possible at each of these stages. The use of automatic equipment reduces greatly the chance of human error. Manual telegraphy began to be replaced by printing telegraphy before 1915 and by facsimile telegraphy in the early 1930s.



Simple diagram of a manually operated telegraph circuit. When the sending key is pressed down, it closes an electric circuit and energizes an electromagnet. This attracts the sounder, which clicks as it is pulled down. As current passes through the circuit to the electromagnet at the other end, this magnet is also energized and the sounder at that end is also pulled down. When the sending key is released, the current is broken. The electromagnet is no longer energized and the sounder is released, making another clicking sound. A corresponding click is made at the other end of the line. In this way a pattern of clicks is transmitted, and it is arranged to form a code. A long key represents a dash. A short contact is a dot.

THE TELETYPEWRITER

In automatic transmission by the printing method, a device called a *teletypewriter*, is used. It looks like a typewriter with three rows of keys. As each key is pushed down in turn, it punches a certain number of holes, forming a distinctive pattern, in a narrow paper tape passing through the machine. The tape is then passed into a transmitting machine. Sometimes the tape passes directly into the transmitter from the teletypewriter. Sometimes the operators feed it in at their convenience when a certain number of messages are to be sent.

Little pins in the transmitting machine press lightly against the tape paper. As the pins come to the holes in the tape, they move down into them just enough to operate small electric switches. The switches cause current impulses to be transmitted over the telegraph wire. The impulse pattern corresponds to the arrangement of the holes in the tape. The impulses operate an automatic typewriter, called a *teleprinter*, at the receiving end of the line. The messages appear in capital letters on long strips of paper, which are then cut and pasted on telegraph blanks.

In preparing a message, the operator types a routing symbol at the beginning of each telegram. After the operator has typed the message on the perforated tape, it passes through an automatic transmitter. The coded symbol prompts a computer at the high-speed message center to route the message to its destination area. Here the automatic teleprinter receives the message and typewrites it.

Many industrial firms and public agencies use some form of teletypewriter or teleprinter exchange service, such as Western Union Telex. Each Telex subscriber is provided with a teleprinter, an associated dial unit, and a nationwide and international

USIA

Teletype room at the U.S. Information Agency's Washington office. The teletypewriter uses automatic transmission by the printing method.

directory of other subscribers with their Telex numbers. A subscriber can get in touch with another subscriber by dialing his number. The connection is completed automatically in many parts of the world.

Facsimile transmission plays an important part today in telegraphy. Facsimile transmission machines, based on the photoelectric cell, can send and receive pictures of telegrams automatically.

MULTIPLEX SYSTEMS

In the original Morse system, only one message could be sent at a time over a wire in either direction. Since even a skilled operator can tap out at most only about thirty words a minute, telegraph transmission often could not keep pace with the great number of messages to be transmitted. More than one message can now be sent over the same wire at the same time through the use of *multiplex systems*.

In the *time-division multiplex system*, the transmission path is divided among several transmitting and receiving devices.

Frequency-division multiplex is based on the generation of electric waves of different frequencies and on the ability of the receiving set to select one desired frequency and to reject all others. Through this method, hundreds of messages can be sent simultaneously over a single pair of wires. The electrical properties of the wires may be improved by shaping one wire into a tube and running the other one through the center of the tube. The structure is known as a *coaxial cable* because the two conductors have a common axis.

Microwave radio beam networks represent an important advance in telegraphic communication. The first commercial network of this type was installed by Western Union in 1945 between New York and Philadelphia. A transcontinental microwave network now exists. Radio towers about 50 kilometers apart are substituted for the familiar pole lines. Antennas equipped with parabolic reflectors transmit radio-telegraph signals in a narrow beam from tower to tower. Unattended repeater stations automatically and instantaneously send the radio-telegraph signals on their way. Thousands of messages can be sent out at the same time.

Telegraphic systems are being used on an ever-increasing scale in combination with electronic digital computers. The messages are in the "language" of the electronic computer—that is, extremely brief pulses sent with great rapidity. Input information is usually presented to the machines as punched tape and the output appears as typed tape. The punched tape can be made to operate a transmitter at one end of the telegraph line, the other end being connected to a central electronic data-processing device. In this way, information from electronic computers in widely separated areas can be transferred to the central device in a form it can use immediately.

The modern telegraph company even provides for voice or record communication. Thus, in a recently established service called *broadband switching*, Western Union offers customer-to-customer connections for voice, data, facsimile, and other types of communication.

Western Union

In multiplex systems that use computers, messages are sent and received with great speed. This machine can give customer-to-customer service.

SUBMARINE CABLES

The transmission of telegraph messages by submarine cable involves special difficulties. The laying of a cable is a time-consuming and expensive task. The interior copper wire must be perfectly insulated from the surrounding salt water. The cable must be strong enough to resist the action of underwater currents. It must also be protected from damage.

The credit for the laying of the first transatlantic cable is due primarily to U.S. businessman Cyrus W. Field and Canadian inventor Frederick N. Gisborne, who had had considerable experience in laying deep-sea cables. As a result of his meeting with Gisborne, Field became interested in the idea of a transatlantic cable. In 1856, he organized the Atlantic Telegraph Company, supported almost entirely by British capital.

Using two ships, he first attempted to lay a cable between Ireland and Newfoundland in 1857. The cable parted 540 kilometers from the Irish coast and was abandoned. In 1858, a second attempt also failed. Later in the year, however, a third attempt succeeded. The first message was sent from Newfoundland to Ireland on August 7, 1858. The cable ruptured less than a month later and was abandoned.

Another cable, laid in 1865, broke at a distance of 1,900 kilometers from Ireland. The next year a new cable was laid successfully, and the cable abandoned in 1865 was picked up and completed. Today the various parts of the world are connected by well over a thousand submarine cables totaling hundreds of thousands of kilometers in length.

The feeble nature of the signals sent through a long cable necessitated the invention of more sensitive receiving equipment. The siphon recorder developed by William Thomson (later Lord Kelvin) in 1867 solved the problem of sensitivity and was used for many years. The instrument consisted of a light coil of fine insulated wire, suspended between the poles of a powerful magnet. Current from a cable was sent through this coil. It represented a dot, in the Continental code, when sent in one direction; a dash, when sent in the other. When current from the cable passed through the coil, it twisted one way or the other, depending upon the direction of the current. A thread attached to one part of the coil pulled a glass tube containing ink across a moving paper tape; thus it produced an undulating line, representing changes in cable current.

The coaxial cable has been adapted to submarine use. In conjunction with amplifiers acting as relays, it provides hundreds of telegraph channels and dozens of telephone channels. A cable of this type has been laid across the Atlantic. It contains dozens of amplifiers, inserted in the cable at regular intervals. They are built into cylindrical housings slightly larger than the cable itself and submerged as part of it. Power for the amplifiers is carried over the cable with the signals. The amplifiers are designed and carefully built to give many years of life before being replaced.

THE TELEPHONE

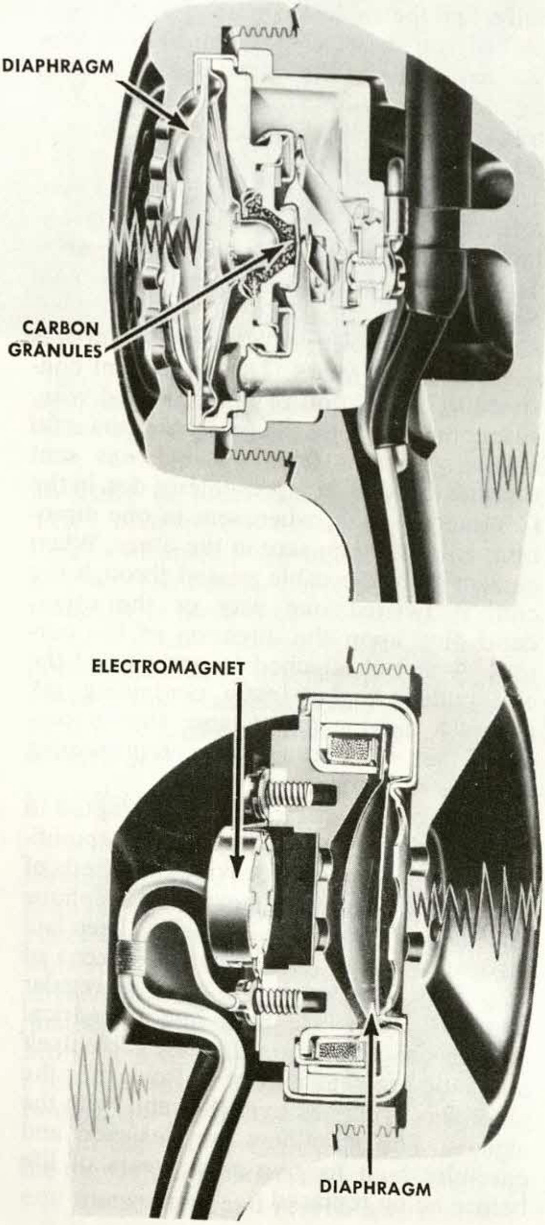
"I'll give you a call tonight."

You must have heard that statement a countless number of times. But did you ever think about what happens when you pick up the receiver and dial a number? Probably not, because the telephone has become such a common fixture in our environment that we take it for granted. Most of us make several calls a day and many of us use the telephone as a business tool. We accept the telephone as it is and for what it is—a necessary "convenience". But, from the day it was born, the telephone has been growing and changing to meet people's changing needs.

THE FIRST TELEPHONE

The first practical telephone resulted from a series of experiments in telegraphy. In 1873, Alexander Graham Bell, professor of vocal physiology at Boston University, became interested in the study of multiple telegraphy. He conceived the idea of what he called a *harmonic telegraph*, a device capable of sending several messages over a single wire simultaneously by means of several pairs of steel springs.

If a telegraph key were closed at the transmitting end, a spring at that end would be attracted by the electromagnet of the transmitter. The spring would be so attached that as it made contact with the electromagnet, it would cause the circuit to be broken. The spring would then return to its original position. As it did so, the circuit would again be closed and the spring would again be attracted to the electromagnet. As the current would be alternately opened and closed in this way, the spring would



Top: telephone transmitter. The modern transmitter has a chamber filled with carbon granules set in back of a diaphragm. Electric current passes through this carbon chamber and the connecting wire. The human voice causes the diaphragm to move back and forth. As it does so, the carbon grains become alternately more and then less loosely packed. This brings about corresponding changes in strength in the current traveling to the receiver. Bottom: the telephone receiver. In the receiver, an electromagnet is arranged so that it attracts a thin iron diaphragm. Depending on the strength of the current reaching the receiver, the diaphragm will be attracted more or less strongly. The vibration of the diaphragm causes the surrounding air to vibrate, thus transmitting the sound.

vibrate continuously at its natural frequency. It would do so as long as the key would be held down. The current in the telegraph line would pulsate at the same frequency as the vibrating spring, since it would be turned on and off and on again as the spring vibrated.

Another spring would be set at the receiver at the other end of the line. It would be attracted to the electromagnet of the receiver as current flowed through; it would spring back as the circuit was broken and would again be attracted to the electromagnet as the circuit was closed again. The two springs would vibrate in unison at opposite ends of the telegraph line.

Bell believed that a number of these spring units could be connected to the ends of a single telegraph line and that several messages could be sent at the same time if each pair of springs were tuned to a different frequency of vibration. He built several models of the harmonic telegraph, but he was never able to make any of these models work satisfactorily.

While these experiments were going on, Bell had suggested the possibility of transmitting speech electrically. On the afternoon of June 2, 1875, Bell's assistant, Thomas A. Watson, was working on the transmitting spring of a short-line telegraph, while Bell was adjusting the springs at the receiving end. One of the transmitting springs had stopped vibrating. Watson kept plucking it to get it started again. Suddenly Bell rushed into the room and cried: "What did you do then?" Bell had heard the sound made by the plucked spring at the receiving end of the line.

This is what had happened. The make-and-break points of the transmitting spring had become welded together. When Watson snapped the spring, the circuit had remained unbroken. As the spring, of magnetized steel, vibrated over the pole of the magnet, it generated a current of electricity that varied in intensity as the air varied in density near the spring.

Bell realized the full significance of this unexpected development. He replaced the spring with a diaphragm that vibrated in accordance with the varying air pressure produced by a human voice. After experimenting with various diaphragm shapes, he developed a transmitter and receiver that transmitted speech fairly well. The first telephone patent was issued on March 7, 1876. It has been called the most valuable patent ever issued in any country.

MANY IMPROVEMENTS

Various improvements were made in the construction of the telephone. The most important one was the substitution of a permanent magnet for the soft iron core that had formerly been used. Other alterations were made in the telephone, resulting in a much simpler and more compact instrument.

In about one century of telephone research, telephone engineers have overcome one by one the barriers to speech transmission. From the very beginning, the progress of the art has been marked by epoch-making advances due to inventions and improvements in apparatus and equipment. Some of the more notable achievements have been as follows:

(1) The development of the *switchboard,* without which no interconnecting group of telephones would be possible. This was the beginning of the *telephone exchange.*

(2) The discovery of the process of hardening copper wire and its application to telephone circuits, thus improving transmission and making long-distance open-wire telephone circuits possible.

(3) The use of *coaxial cables,* thus reducing the disturbance caused by adjacent power circuits or other telephone circuits and greatly improving transmission.

(4) Development of automatic switching systems, opening the way for tremendous expansion in the fields of local and long-distance telephony.

(5) Radio relay has developed as a supplement to wire communication until at present it provides millions of kilometers of telephone circuits all over the United States.

(6) Development of the transistor. The small size and low power requirements of this electronic device opened the way for

A.T. & T. Co.

The cableship *Long Lines* has laid many thousands of kilometers of undersea telephone cable, but global satellite systems are rapidly supplanting cable use.

more compact and efficient telephone systems.

(7) The transposition of telephone circuits, thereby minimizing the interference of other telephone circuits and of electric light and power wires.

(8) The development of the *underground cable*, making possible the removal of pole lines from the main thoroughfares of cities, and the *aerial cable*, reducing the number of crossarms and the size of the poles.

(9) Improvement in the designs and methods of manufacture of cables for local exchange use, thus making it possible to increase greatly the number of wires that may be placed within a cable sheath of given size. By employing smaller wires, the maximum number of wires carried in a single cable has been increased to several thousand pairs.

(10) The development of magnetic alloys. Permalloy, a magnetic alloy composed of approximately 80 percent nickel and 20 percent iron, has made possible a reduction in the sizes of telephone cables and a decrease in the cost of the loading coils required, and has brought about savings in a great many other types of telephone apparatus.

(11) Developments in *submarine cables*, including the use of coaxial structures and submerged repeaters capable of operating under deep-sea pressures.

(12) The use of microwaves for signal transmission.

(13) The development of the laser and research in fiber optics. Uses of the laser include carrying messages over optical fibers. Bundles of optical fibers can carry many more messages than can conventional cables. A helium-neon laser, for example, pulsing millions of times per second, can transmit many thousands of phone calls simultaneously over cable made of optical fibers.

(14) The development and widespread use of communications satellites.

Portable computer terminals can be used to communicate with distant computers via regular telephone lines. Computer terminals can be used at home or anywhere there is a phone.

IBM

MAKING CALLS

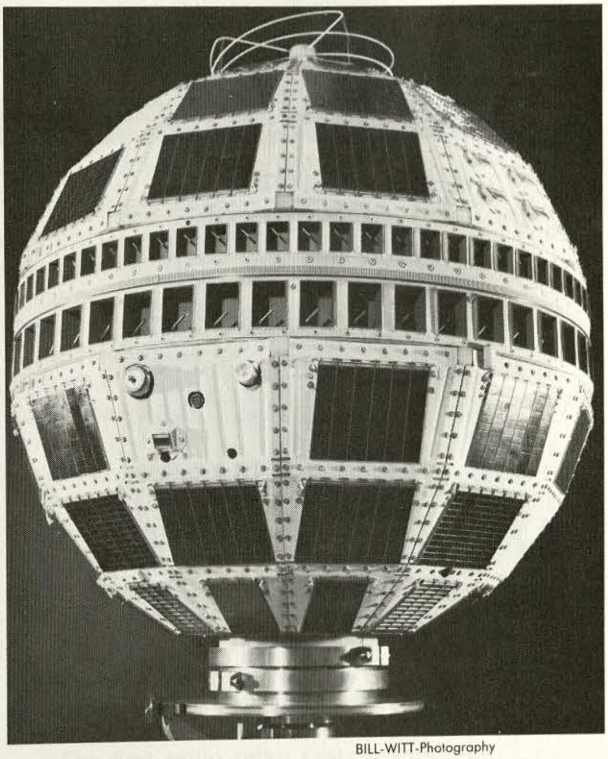
In the earliest telephone systems, one person could call another only if the two phones were directly connected by a separate wire. Nowadays *central offices* permit calls to be placed anywhere in the world with only one line leading from the subscriber's phone to the office. A vast network of *trunk lines* joins the exchanges in different cities and countries, spanning continents and oceans.

Automatic Systems. Various types of automatic switching equipment are used. The subscriber spins a dial or pushes a button on his telephone in accordance with the letters and figures of the number desired. As the number is selected, a mechanism connected to it alternately opens and closes the circuit a certain number of times. The electrical impulses are transmitted to dial apparatus in the telephone central office. Push buttons generate signals that are interpreted in the central office.

Various types of dial equipment are in use. The most common type, called *step-by-step*, is found mostly in smaller locations, where switching arrangements are fairly simple. When the user lifts the receiver, equipment in the office connects his telephone line to a device called a *selector switch*. The caller hears a dial tone and begins dialing. Other selector switches advance the call as each successive letter or figure is dialed. When the final number is dialed, the bell on the called telephone begins ringing. Step-by-step equipment was introduced in 1892; extensive use began about 1919. This equipment has been succeeded by the faster, more efficient crossbar system that was developed in the late 1930's.

In *crossbar systems* there are two kinds of apparatus: the control equipment and the switching network. The latter network sets up talking paths under the direction of the control equipment.

On a call dialed through some types of crossbar equipment, connections are not set up until the complete number is dialed. On other types, the called office is selected after the first three digits are dialed. At that time the control apparatus in a split second determines the correct path the call must take to reach the desired telephone. Once the path has been determined, the equipment closes the appropriate switches and the call goes through instantaneously.



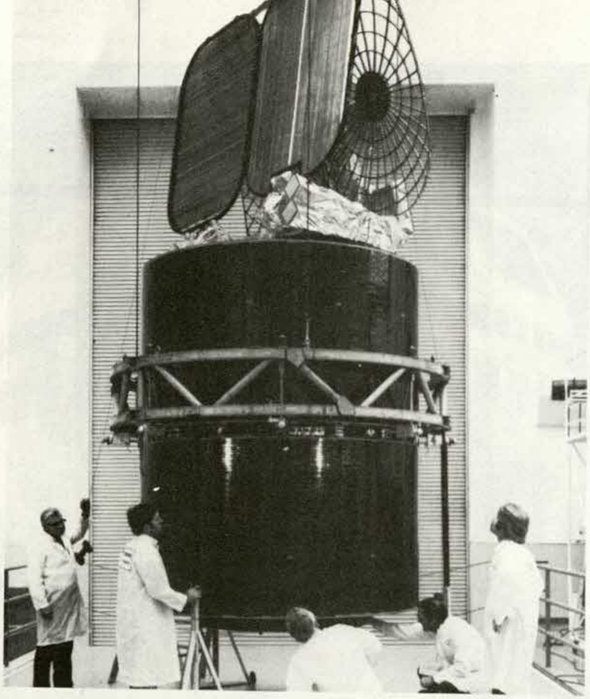
BILL-WITT-Photography

The experimental commercial satellite Telstar I, able to retransmit 60 calls at once, facilitated the first coast-to-coast telephone calls via satellite.

If the call is to an out-of-town point, the control equipment places it on a circuit to the distant office. Control apparatus in that office sets up the appropriate circuits over which the call can be completed.

LONG-DISTANCE LINES

For many years after the invention of the telephone, speech transmission over lines more than a few hundred kilometers in length proved impossible. Even over shorter lines it was frequently difficult to transmit speech clearly. In ordinary speech we recognize syllables, words, or voices by the special blend of high and low frequencies in the sound waves the speaker produces and by the order in which they follow one another. If this balance is altered, making some frequencies stronger and some



Comsat General Corp.

One of the three Comstar communications satellites. Put into orbit to provide U.S. domestic service, each can relay 36,000 simultaneous telephone conversations.

weaker (*frequency distortion*), or if the sequence is changed (*delay distortion*), the character of the voice is changed. Individual words may become unintelligible, and even whole phrases may be quite difficult to understand.

Frequency distortion was a major problem in long-distance transmission. As voice currents passed along a great stretch of wire, the higher frequencies were attenuated, or weakened, more rapidly than the lower ones. At the end of a long line, what the listener often heard was only an unrecognizable remnant of the original sound.

The cause of this distortion was well known. Two insulated electric wires, lying very close to each other, behave somewhat like a capacitor. This capacitor is continuously being charged and discharged for each half-cycle of voice current transmitted. The charging current is drawn through the line wires. Because the line wires have resistance, a certain amount of heat is produced. Each time the capacitor is charged, the same amount of electricity is required. But the higher the frequency, the shorter the charging time and the greater the current that must flow to provide the charge. The greater the current, the more the heat loss produced in the line wires. Thus the higher frequencies are not transmitted as well as the lower ones.

In 1900 a U.S. physicist, Michael I. Pupin, managed to counteract the capacitor effect by placing inductance coils in the lines at certain calculated intervals. The voice frequencies were then all transmitted about equally well, with almost no distortion. Pupin's idea, known as *coil loading*, was adopted by the telephone companies and increased the range of transmission by three or four times.

There were many other problems in long-distance transmission. Coil loading had greatly extended the range of telephone transmission, but still greater ranges were needed, and better voice transmission was also required.

REPEATERS

Telegraph companies used mechanical *repeater* elements in their lines to restore the energy of signals. These were actually electromagnets. However, they were too sluggish and inefficient to reproduce the broad range of frequencies used in telephony.

The problem was solved in the early 1900's. After years of experimentation, special equipment was finally developed for adapting the *audion,* or three-electrode, *electron tube* for utilization as a telephone repeater.

Here was a flexible instrument that would amplify the energy of electrical currents while maintaining the original frequency patterns with remarkable fidelity. Energy for the tube could be drawn from any source of direct current. These tubes have been replaced by transistors.

The development of an amplifier that would operate under deep-sea pressure for long periods of time without attention paved the way for the first deep-sea ocean telephone cable system. The system was laid across the Atlantic between North America and Europe in 1956. In later years additional telephone cables have been laid in other areas under the ocean.

THE CARRIER SYSTEM

In the early 1900's, the message-carrying capacity of long-distance lines was increased by the use of *phantom* circuits, in which two pairs of wires are made to carry three calls simultaneously. Soon after, a system of multiplex telephony was developed to permit simultaneous conversations to be conducted over a single pair of wires. This system, first introduced commercially in the United States in 1918, is known as *carrier telephony*. It is based on the principle of modulation that is used for radio broadcasting.

Just as a sound wave may carry vibrations of many different frequencies at the same time, so an electrical circuit may carry a complex alternating current that is actually made up of many separate currents, each having a different frequency from all the rest.

In the carrier system, each of these different currents is composed of two parts: the *carrier* and the *message*. The message, of course, is the voice current from some subscriber's telephone transmitter. The carrier originates in an electronic oscillator. It is a current alternating at a particular high frequency, above the range of voice currents.

In one arrangement, the voice current is combined with the carrier in a device known as a *modulator*.

Voice currents from other phones can be transmitted on the same line, provided that each message is combined with a carrier of different frequency. Each frequency serves to identify the individual call it carries as it is transmitted together with others through a single cable. At the end of the line, a filtering device separates the calls according to the carrier frequencies and then sends each one of them along the proper route.

Finally, before reaching the receiver at its destination, each telephone call goes through a *demodulator*, which suppresses the carrier frequency, leaving only the voice current. Carrier telephony has played a key role in the striking advances in long-distance communications.

RELAY SYSTEMS

Microwave radio relay systems are an important development in the field of carrier telephony. They supply a large number of telephone circuits for long-distance calls and the broad-frequency bands needed to transmit television programs. Radio relay systems consist of relay towers located within line-of-sight distances from each other. Radio waves at frequencies of several thousand million hertz, called *microwaves*, are sent from one tower to the next, and so on.

At each relay station the signals are amplified and sent on to the next. The microwave system provides as many as six or more broad-band communication channels in each direction. A pair of these channels going in opposite directions can carry as many as several thousand conversations or two television programs.

The first radio relay system was built in 1947 between New York and Boston. Since then these systems have provided millions of kilometers of telephone circuits, which is a substantial proportion of the nation's long-distance circuits.

In 1957 the Bell System put the country's first commercial *over-the-horizon-microwave system* in service. The over-the-horizon system differs from conventional microwave installations in that the signals do not follow a line-of-sight path. In a process called *tropospheric scatter propagation*, a small fraction of the energy in the transmitted radio wave is deflected back to earth at points beyond the horizon. No intermediate stations are needed.

Communications satellites have added a new dimension to long-distance communications. Rows of microwave antennas receive signals from various stations and relay them back to earth.

Optical transmission systems, such as laser and fiber optics, can also be adapted for telephone transmission. Their major advantage is that they can carry many more simultaneous messages than any coaxial cable. There are many problems that must be worked out, however, before these systems can be used commercially.

© Frank Siteman/Taurus Photos

A late-night radio disc jockey acts as broadcaster, program manager, and engineer for his own program.

RADIO

by Robin Lanier

One of the most enthralling stories in 19th-century science is that of the discovery of electromagnetic radiations, which led to the development of radio and television, now so much parts of all our lives. These radiations can travel very long distances through space. They include light and radio waves as two forms. The existence of the family of radiations was first predicted by the Scottish physicist James Clerk Maxwell from his mathematical studies of electric circuits in the 1860's. In the late 1880's, seeking to find out if Maxwell's prediction was correct, the German physicist Heinrich Hertz managed to create a radio wave and send it through space across his laboratory. Many other scientists and experimenters then began to work with radio waves.

A high point in this early period came in 1901 when the Italian inventor Guglielmo Marconi built very large equipment to produce strong radio waves, and used the waves successfully to carry signals from England to Newfoundland, across the North Atlantic. Marconi's dramatic proof of the long-distance carrying power of radio waves was hailed in newspapers around the world, and was the opening curtain for the age of radio.

In addition to radio waves and light, the family of electromagnetic radiation includes radiant heat, X rays, gamma rays, and cosmic rays. Each of the waves vibrates steadily as it travels through space. The number of vibrations per second, called the *frequency* of the radiation, is what distinguishes one member of the family from another. Radio waves have a group of frequencies lower than the others, radiant heat has the group next higher, visible light is next, and so on.

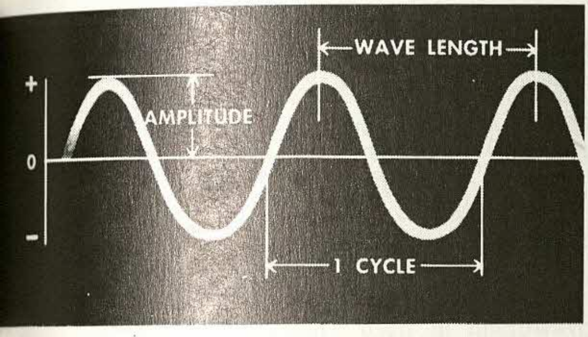


Figure 1: the characteristics of an alternating current. From zero, the current builds up to a peak in the positive direction. Then it is gradually reduced again to zero. Next it reverses and builds up to a peak in the negative direction, then falls back to zero again.

As the frequency is changed, the way the radiation performs changes, too. Radio waves at the low end of their group of frequencies, or *spectrum,* can penetrate some solid substances, and tend to spread out in all directions from their source. But as the frequency of radio waves is changed to bring them closer to the frequency of light, the radio waves begin to act more like light, traveling in straight lines and being blocked by most solid substances.

As the frequency is increased on up the scale, the way the radiation behaves keeps changing, often in unexpected ways. X rays, as everyone knows, can go through almost all solid substances; the frequency of X rays is much higher than that of light.

Italian inventor Guglielmo Marconi developed the concept of using radio waves for communications. In 1895 he conducted his first successful tests.

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PRODUCING RADIO WAVES

Radio waves are created and projected into space by sending strong alternating electric currents to large metal structures, called *transmitting antennas,* which are supported high in the air. It is as though the transmitting antenna were the nozzle of a hose spurting electric power in a stream into the air. If the alternations in the electric current take place at a high enough rate, corresponding to one of the frequencies in the radio group, and if the antenna structure is correct, a large part of the power in the current will take off into space as a radio wave.

ALTERNATING ELECTRIC CURRENTS

All atoms have among their particles one or more electrons, which are the fundamental units of electricity, each carrying a tiny amount of negative electric charge. Metals are good conductors of electricity because a fair number of their electrons are free to move inside the metal. If an electric pressure, or voltage, is applied at one end of a circuit, electrons will be forced to move around the circuit, and this motion is an electric *current.* The current can take power from one end of the circuit to the other. For example, the battery in a flashlight pushes electrons through the metal connections and through the bulb, which lights up from the power brought by the electron flow, or current.

Electric currents used today are mainly of two forms, direct and alternating. *Direct current* flows around a circuit always in the same direction. *Alternating current* goes first one way and then the other, reversing direction very rapidly.

We can represent the characteristics of an alternating current by the diagram in Figure 1. From zero the current builds up to a peak in the positive direction. Then it is gradually reduced again to zero. Immediately upon reaching zero, the current reverses and builds up to a peak in the

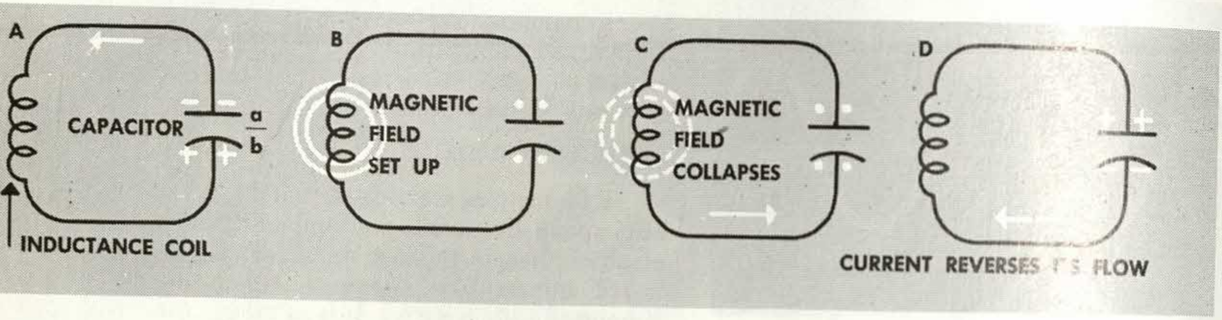


Figure 2: a simple oscillator circuit at work. The circuit consists of an inductance coil and a condenser linked together. (A) The condenser has received an electric charge. Plate *a*, with a surplus of electrons, is negative. Plate *b*, with an electron deficiency, is positive. When the circuit is closed, electrons flow from *a* toward *b* through the inductance coil, since they cannot pass through the material separating the plates. (B) A magnetic field is set up. (C) Field collapses and electrons pile up at plate *b*. (D) Current reverses itself, and electrons flow back from plate *b* to plate *a*.

negative direction. Again it returns to zero, to repeat the process as long as it continues to flow. The strength of the current at its peak for a given pulse is called its *amplitude*. The distance from one positive or negative peak to the next represents its *wave length*. A completed back-and-forth movement is a *cycle*.

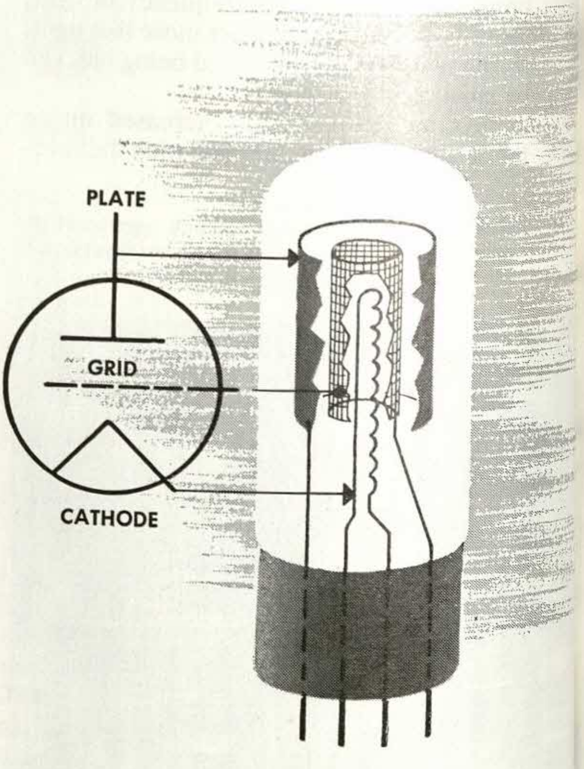
It might seem that alternating current would be more trouble to use than direct current, but the fact is that for many uses—lighting homes, running refrigerators and washers, driving motors in factories, and many others—alternating current is more convenient, for a number of technical reasons. Thus, most of the huge quantity of electric power we use today is alternating, and the rate of alternation, or frequency, in the United States is almost always 60 times per second (60 hertz, or Hz, named for Heinrich Hertz).

GENERATING THE RADIO-FREQUENCY CURRENTS

Radio broadcasting would be far simpler if we could just send the power we get from the local utility at 60 Hz up the antenna. But at this low frequency the power will not take off for long trips in space. It must alternate at very much higher rates.

Each current cycle produces a single radio wave. Consequently, the frequency of the alternating current corresponds ex-

Figure 3: the structure of the three-element vacuum tube called a triode. At left is the way in which a triode is represented diagrammatically.



actly to the frequency of the radio waves it generates. The frequencies used in radio range from about 100,000 hertz (100 kilohertz, or 100 kHz) up to more than 100 million hertz (100 megahertz, or 100 MHz). Standard AM broadcasting is in the band from 500 kHz to 1,600 kHz; FM radio is between 88 MHz and 108 MHz. Television goes up to about 800 MHz. Even higher frequencies, up into the gigahertz (billions of hertz) range, are used in microwave communications systems for telephone and data transmission from one point to another.

How do we get electric power to alternate at such high rates? The early experimenters (Hertz and Marconi among them) often used a *spark gap,* an electric circuit with a small gap across which the voltage would jump. If the proper circuit apparatus is connected to the gap, the current across the gap will reverse direction at extremely high frequencies, generating a radio wave.

Spark gaps were widely used in early radio transmitters on ships and elsewhere. But the gaps were hard to control and produced energy at many frequencies simultaneously, causing interference among transmitters. An alternative is to use an oscillating circuit, or *oscillator*.

Westinghouse's Aeriola, Jr., was the first popularly-priced home radio receiver. It used headphones and had a range of 20 to 25 kilometers.

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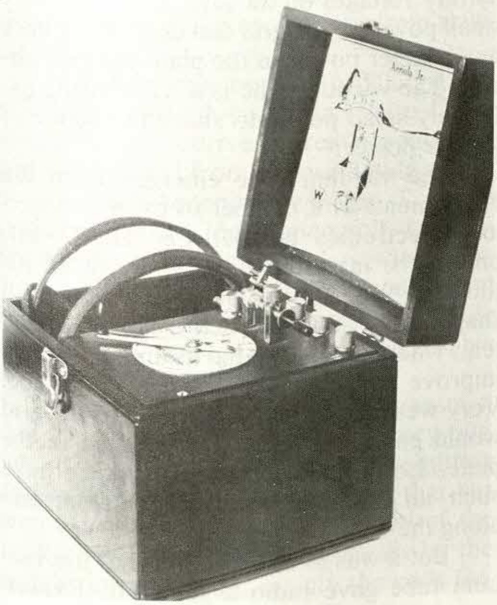


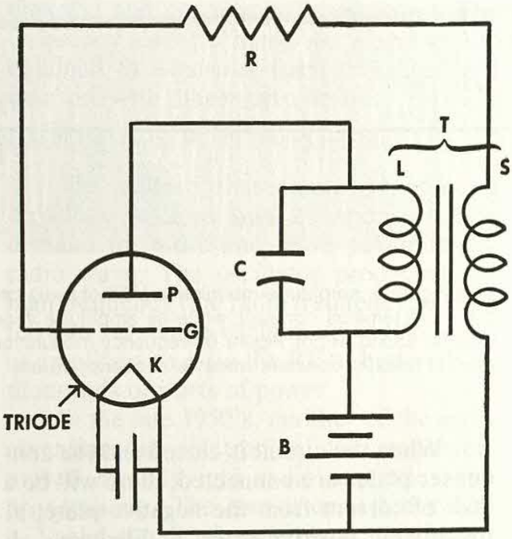
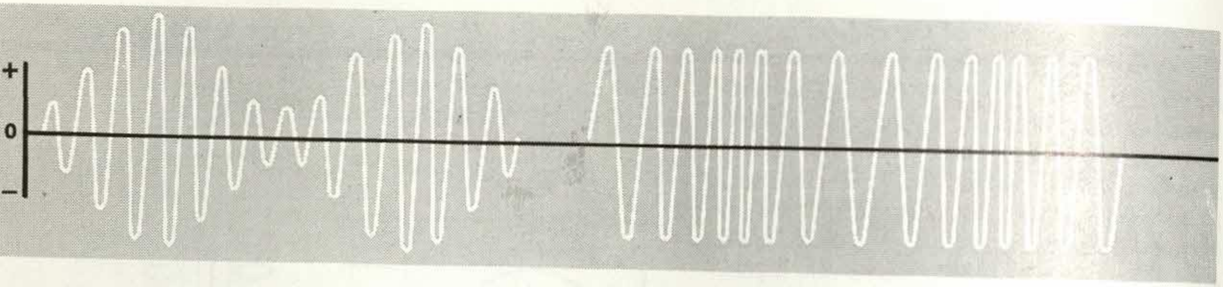


Figure 4: diagram of simple oscillating circuit with a triode. In the diagram, *B* is the battery, *C* the condenser, *G* the grid, *K* the cathode, *L* the inductance coil, *P* the plate, *R* the resistance, *S* the secondary winding, and *T* the transformer.

Each oscillating circuit has an *inductance coil,* or *inductor,* and a *capacitor,* or *condenser*. The inductance coil consists of a wire wound around a hollow cardboard tube. Whenever current is passed through the coil, a magnetic field is set up around it. The condenser is made up of two or more plates of tin foil, brass, or aluminum. The plates are separated by a substance such as air, glass, paper, mica, or oil that will not conduct electricity. It is known as the dielectric. The condenser stores electric charges up to a certain capacity when a steady voltage is applied to the terminals of the device.

The simple oscillator circuit shown in Figure 2 shows an inductance coil and a condenser hooked together. The capacitor has received an electric charge. Plate *a* is negative, plate *b* positive. This means that there is a surplus of electrons at *a* and an electron deficiency at *b*.



Left, Figure 5: amplitude modulation (AM) of radio carrier current. The frequency of the wave remains constant, while its amplitude varies according to nature of the original sound. Right, Figure 6: frequency modulation (FM), in which amplitude of current remains constant while its frequency varies.

When the circuit is closed and the condenser plates are connected, there will be a flow of current from the negative plate, *a*, toward the positive plate, *b*. Electrons always flow from a place where they are in excess to a place where they are deficient. As the electrons pass through the inductance coil on their way to *b*, the rate of flow will be retarded at first as a magnetic field is set up around the coil. Then this field will collapse and the current will continue to flow through the circuit in the same direction as before.

There will again be a slight lag as the electrons pile up at plate *b*. The formerly positive plate will become negative, while the formerly negative plate will be positive. When the condenser is fully charged, current will flow from plate *b* toward plate *a* and again will pass through the inductance coil, setting up a magnetic field. The electrons will flow back and forth between *a* and *b* at an extremely rapid rate. Their oscillations will make up a high-frequency alternating current.

We can produce any desired frequency within certain limits by making adjustments in the induction coil or the condenser. We can change the length of the inductance coil or the number of turns of wire or the type of core. We can add more plates to the condenser or bring the plates into closer contact with each other.

The to-and-fro movement of current in the circuit does not go on forever. The oscillating electrons lose energy in overcoming the resistance of the inductance coil winding and the connecting wires. It is necessary, therefore, to furnish a new source of energy that will keep the oscillations from slowing down or stopping. We can do so by inserting a *triode*, or three-element vacuum tube, in the oscillating circuit.

The construction of a triode is shown in Figure 3. The hot cathode emits electrons that, as negative units of electricity, are attracted to the positively charged plate. Plate and cathode are connected through an external circuit. The electron flow through the tube constitutes a current around this circuit.

As they pass through the vacuum, the electrons are easily controlled in number by tiny voltages on the grid. Thus, the very small power in the grid can control the very much larger power in the plate-cathode circuit. The vacuum tube is a *relay*, using extremely small power to shape the action of greater power.

The vacuum tube emerged from the experiments of a number of people. American electronics pioneer Lee De Forest, one of the main developers, produced his tube in 1906. It was brought to practical shape mainly by the Bell Telephone system, where it was needed as an amplifier to improve long-distance telephone service. Very weak telephone signals fed to the grid would emerge greatly strengthened in the plate. Long-distance telephone lines have such an amplifier every few kilometers along the way.

But it was as an oscillator that the vacuum tube gave radio a giant lift. Experi-

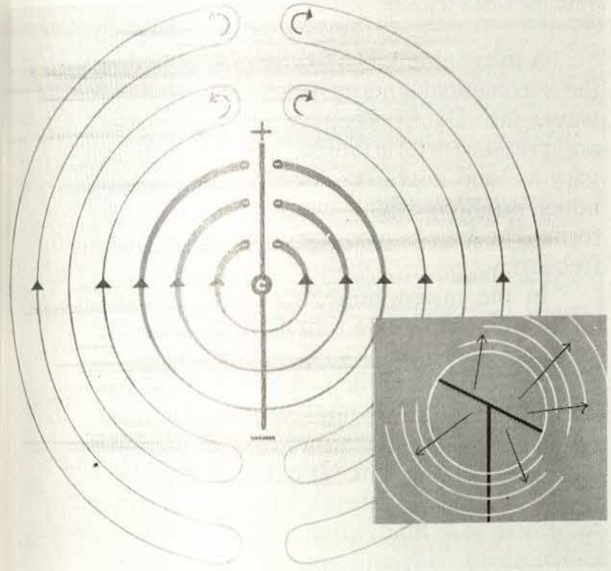


Figure 7: propagation of radio waves from dipole antenna. C in diagram is the current source. Inset shows how the radio waves spread outward.

menters, among them the great American radio inventor Howard Armstrong, found that if part of the energy in the plate circuit was fed back again to the grid, the tube would produce very high frequency alternations that could be tapped and used. The triode thus provides the additional energy required to keep the oscillations from slowing down.

We show one type of oscillating circuit, complete with triode, in Figure 4. The voltage used to drive current through the grid is extracted from the oscillating circuit by means of a secondary winding, *S*, on the same core as the inductance coil, *L*. Voltage is induced in this secondary winding by the action of the transformer, *T*. By about 1913, vacuum tube oscillators had made long-distance radio communication reliable and practical.

It is highly desirable in radio transmission to have a very steady frequency output, in order to ensure that a transmitting station will keep to the frequency that has been assigned to it. The frequency of the oscillation can be controlled closely by the devices in the circuit, mainly the coils (inductors) and condensers (capacitors). The frequency can be made very stable and confined to a narrow band that does not interfere with other transmitters.

OSCILLATORS PLUS AMPLIFIERS

The pattern that emerged for radio broadcast stations was a response to the demand for more and more power in the radio wave. The oscillator producing the high frequency (the radio frequency, or RF) fed into very large vacuum tubes that acted as amplifiers to raise the RF to hundreds or thousands of watts of power.

In the late 1950's, another of the great inventions in electronics, the transistor, moved steadily into radio and television broadcasting. The transistor, often called a "solid-state" device or a "semiconductor," is an electronic relay like the vacuum tube. But the electrons subjected to control are moving through the interior spaces in crystal substances rather than through a vacuum.

The solid-state electron relay has a number of advantages over vacuum tubes. It does not wear out, and it uses less power, puts out practically no neat, is compact and inexpensive, starts up instantly, and permits a wide range of frequencies. Most of us first came in contact with transistors in portable radio receivers, where the small size and weight and low power demand were splendid qualities.

Today transistors are used throughout the circuitry of radio and television transmitters, except for the final amplifier in very-high-power transmitters. Transistors have been essentially low-power devices, but new designs handling more and more power are being made, and many medium-power radio transmitters are entirely solid-state.

BROADCAST STATIONS

Thus, we have fully developed radio and television broadcast transmitters that can operate at any frequency in the band at a wide range of power levels. In the United States each broadcast station given a license is assigned both a frequency and a power level by the Federal Communications Commission. These assignments are worked out in a way to minimize interference among stations. With about 8,000 radio stations and about 800 television stations in the country, this is like solving a jigsaw puzzle, but the job has been done effectively over the years. In Canada frequencies are allotted by the Telecommunication Division of the Department of Transport.

Radio stations have distinctive call letters. Stations in the United States use the letter "W" or "K" as the first of their call letters. The first letter of Canadian stations is "C." Usually, the choice of the other call letters is left to the broadcasting station. These additional letters sometimes stand for the initials of the company that runs the station. For example, in New York City, WRCA is operated by the Radio Corporation of America, WCBS by the Columbia Broadcasting System, and WABC by the American Broadcasting Company.

PROGRAM SOURCES

The RF power put out by the station is called the *carrier,* because it literally carries the station's program to the listener's receiver. The frequency of a radio or television station, which we use in setting our receivers to tune in the station, is the carrier frequency.

The program to be carried can originate in different ways. It can be music or speech picked up in the station's studios, or in a concert hall or other public place, or even on the street or in a moving vehicle. When the program comes from microphones outside the station, it can be brought in by telephone lines or by special radio equipment designed especially for such *remote* pickups. The remote crew has small portable transmitters, usually effective for about 15 kilometers, and the program is picked up by special receivers in the station's studios.

In all cases, whether the program comes from microphones or from telephone lines and such, the program is in the form of electrical signals that rise and fall in step with the original "information"—voice, music, or other sounds.

THE MICROPHONE

A microphone is a device that converts the mechanical energy released by sound waves into electrical energy. Sound waves are pressure vibrations. Their amplitudes vary as loud notes produce peaks and soft notes produce slight bumps in the wave form. The waves also vary greatly in their frequency.

In the microphone, the sound waves strike a diaphragm—a thin disk capable of a small amount of back-and-forth movement. The motions of the disk correspond to the oscillations of the sound waves. The diaphragm is connected to an electric circuit. As it moves to and fro, it modifies the electric current flowing through the circuit so as to produce a fluctuating pattern. This is called an audio-frequency current, because its fluctuations have the same frequency as the sound waves at the broadcast source. *Audio* is a Latin word meaning "I hear."

The current output of the microphone is very feeble and could not be transmitted more than a few feet from the microphone. It is necessary, therefore, to amplify the current. Each microphone that is used to pick up a program has its own separate preamplifier located in the control booth adjacent to the studio. It is called the preamplifier tube to distinguish it from other stages of amplification that come later in the broadcasting process.

From the preamplifier, the current is led to a *fader,* or microphone volume control, located on a panel in the control booth. The various microphone circuits are mixed. That is, they are combined into one overall program circuit. Further amplification puts the current through as many stages as are necessary. The sounds from all the microphones used on a program are united in one clear, balanced channel. The current is then carried from the studio to the transmitting station through specially constructed telephone circuits.

COMMUNICATIONS SATELLITES

Other sources of programming include recordings of every kind, telephone connections to interviews at political or other

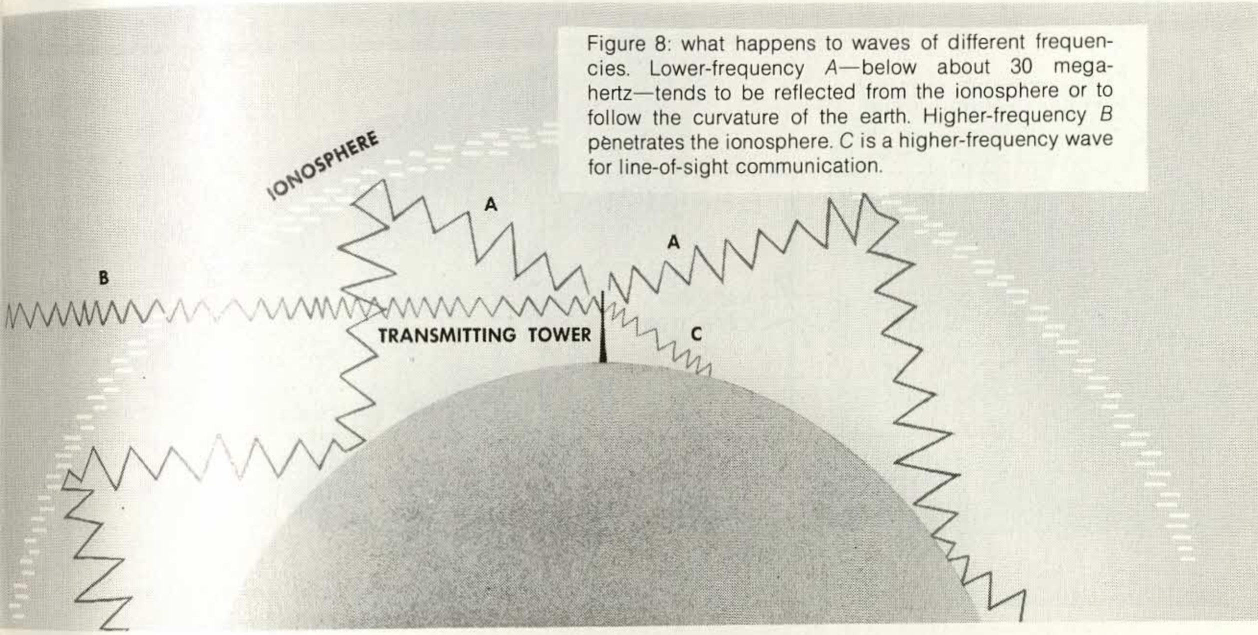


Figure 8: what happens to waves of different frequencies. Lower-frequency *A*—below about 30 megahertz—tends to be reflected from the ionosphere or to follow the curvature of the earth. Higher-frequency *B* penetrates the ionosphere. *C* is a higher-frequency wave for line-of-sight communication.

gatherings, network programs that come in over long-distance telephone lines, and programs relayed to a station's studios by communications satellites.

The satellites are transforming the way programs are distributed to radio and television stations. The communications satellites have been sent into earth orbit by rockets and revolve around the earth at a height of 35,890 kilometers. At this altitude, the satellite is geostationary, going around the earth in the same period at which the earth turns and remaining above a fixed point on its surface. It is as if you ran around a turning merry-go-round at the exact speed needed to stay right opposite the same horse all the time.

A radio or television signal sent up to a satellite is automatically retransmitted toward the earth, but since the satellite is so high, the signal can reach a large area of the earth's surface. If the signal were sent directly from the transmitting station, it could not reach far around the curvature of the earth. The satellite is in a position to "spray" about one-third of the earth's surface.

The satellites relay radio and television programs to stations in all parts of the country at relatively low cost with high quality. They are making long-distance telephone lines obsolete for this purpose. The station wishing to use programs from a satellite employs a special receiver to bring the satellite signal in, and it is fed from the receiver into the studio control equipment.

PUTTING THE PROGRAM ON THE CARRIER: AM AND FM

Whatever the source of the program, the electrical signals representing that program are fed into the big control *consoles* in the studio. Here the volume can be set, the sounds enhanced in various ways, and the program turned on and off at the proper times. These sloping "boards," with their rows of knobs and switches, allow the operator to adjust a number of programs at once and to choose the one to send to the carrier for projection over the air.

The signals representing the program are loaded onto the carrier oscillations in the transmitter, in a process the engineer calls *modulation*. This means that some feature of the carrier is varied in step with the program signals. This variation is carried to the receiver, which recovers from it a close copy of the original material.

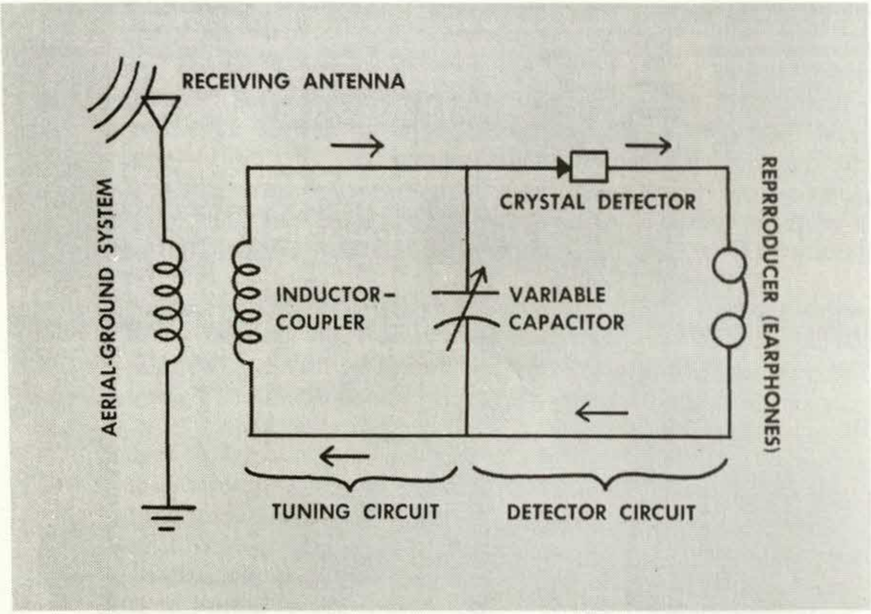


Figure 9: simple crystal radio circuit, showing the four essential parts of a receiver—the aerial-ground system, the tuning circuit, the detector circuit, and the reproducer. Note that earphones are used here.

There are two kinds of modulation in common use in radio broadcasting. *Amplitude modulation* (AM) means that the strength of the carrier varies in step with the program information (Figure 5). *Frequency modulation* (FM) means that the basic frequency of the carrier varies in step with the program information (Figure 6). FM, as most readers will know, has proved to have better sound quality and has become a dominant force in American broadcasting, although quite a few older stations still use AM for local programs that are well established with large audiences. FM is comparatively free from the interference that often mars AM signals. It offers more natural tone reception than does AM. Many receivers have a combined circuit, so that one can change from AM to FM by throwing a switch.

PRODUCING RADIO WAVES

After the program current from the broadcasting site has been combined with the carrier current generated at the transmitting station, the resulting modulated carrier current—AM or FM—is fed to the antenna wire of the transmitting tower. Here it will be converted into radio waves—modulated carrier waves—that will be sent out into space. The transmitting antenna is wire or wires stretched between two points at some distance above the ground. Radio waves emanate from this antenna in the same way as heat waves do when they spread out from a radiator.

Figure 7 shows a dipole transmitting antenna at work. This is one of the most common types. It consists essentially of two vertical wires with the current source —*C*, in the diagram—set between them. Alternating current is flowing through the antenna. During the first half-cycle of current flow, the electrons stream out of one wire, marked with a negative charge in the diagram, and into the other wire, marked with a positive charge. Since the two wires have opposite charges, they may be considered as two plates of a condenser, with the surrounding air as the dielectric. As the current flows, a field is set up between the opposite plates, as shown by the lines of force on the diagram. The current then dies down to zero, and the field collapses back into the wires. Before the last line of force can reach the wire, the current has begun to go through its second half-cycle in the opposite direction, and another field

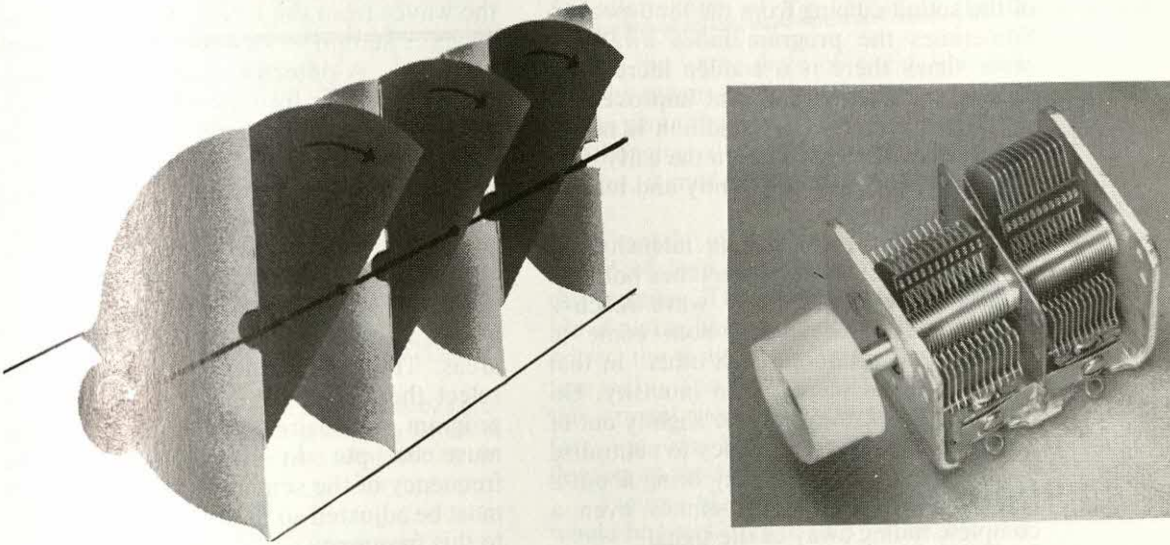


Figure 10: variable condenser. Right, actual condenser. Left, diagram shows that one set of plates is stationary and the other can be rotated.

has formed. The remaining lines of force from the first field are then pushed out by the second field and become detached from the wire. This process is repeated over and over again. The result is that a radiating stream of lines of force is moved out into space at a speed of 300 million meters per second. This stream—a moving dielectric field—produces a magnetic field, which is at right angles to it. Together they make up a radio wave.

RADIO WAVES IN SPACE

Radio waves spread out from their source in all directions like the water ripples you see after you drop a stone into a pond. As the waves get farther away from the transmitting tower, they become weaker. Some of them—ground waves—travel along the earth's surface. Others —sky waves—are radiated straight out into space.

As ground waves travel, they set up induced currents that flow through the ground. In this way they lose energy and are gradually absorbed. Waves of the higher frequencies lose more power in this way than do the waves of the lower frequencies. Intervening hills, buildings, and trees increase the absorption and prevent the signals from being received strongly.

The sky waves that radiate into the upper atmosphere penetrate beyond the stratosphere to the extensive layer known as the ionosphere. In the ionosphere the gases of the air are ionized by the action of ultraviolet rays from the sun. The ionosphere is a very important factor in radio transmission and reception. A certain percentage of the radio waves penetrates the ionosphere and never returns to earth. Waves that do not enter the ionized regions are reflected to the earth and then bounce back to the ionosphere. The waves will travel in this way back and forth between the earth and the ionosphere until they are completely absorbed. (See Figure 8.)

The ionosphere changes height from day to night and during different seasons of the year. Radio reception is better at night and during the winter months because the absorption of the waves is reduced at such times. It has been found that absorption reaches its maximum at a frequency of about 1,400 kilohertz.

Ground waves and sky waves may combine their effects in such a way as to cause undesirable effects in the intensity of the sound coming from the loudspeaker. Sometimes the program fades away. At other times there is a sudden increase in loudness. With the constant improvement in radio receivers, this condition is not so prevalent as it used to be. In the early days of radio it occurred frequently and marred radio reception.

Undesirable changes in intensity are due to several factors. Sometimes both the ground wave and the sky wave reach a receiving set. They may both come in together and reinforce each other. In that case the signal increases in intensity. On the other hand, they may be slightly out of step and may have a tendency to neutralize each other. In this way they bring about a loss in intensity and sometimes even a complete fading away of the signal.

Fading and increase in intensity may also be due to conditions arising in the ionosphere. Changes in this portion of the atmosphere can cause undesirable variations in the sky wave. Such variations may also be due to the interaction between two sky waves. One of these may reach the receiver in one hop. Another may hit the ionosphere at a different angle and may arrive at the receiving set in two hops. Here again, if the two waves arrive in step with each other, the signal will be loud. If out of step, they may cancel each other.

THE RECEIVER

Receivers come in many shapes and sizes, but nearly all have the same general design. An aerial-ground system collects the waves from the air. A tuner selects the wave or station to be received and rejects all others. A detector changes the energy of the wave to a form in which it can operate the reproducer. A reproducer changes the wave energy to a form that our senses can perceive. In Figure 9 we show these four elements in a simple crystal radio set.

THE TUNING CIRCUIT

Each transmitting station sends out waves of a different frequency within local areas. The tuning circuit, or tuner, must select the frequency of the station whose program we desire to hear. The receiver must be put in resonance with the frequency of the sending station. That is, it must be adjusted so that it will respond only to this frequency.

In a tuning circuit, we match the frequency of the incoming signal by means of an inductor and a condenser, hooked together. The inductor is fixed. The condenser is variable. One set of plates is stationary and the other can be rotated (Figure 10).

Once you have tuned your set to the carrier, the action starts with stages that strengthen the carrier as it comes in with the program, since it is likely to be weak after its trip. At this point the incoming carrier, loaded with the program, is mixed with a signal from a *local oscillator*, a miniature transmitter built into the receiver. According to the mathematics of such mixtures, a third carrier emerges that is the difference between the two, and this is

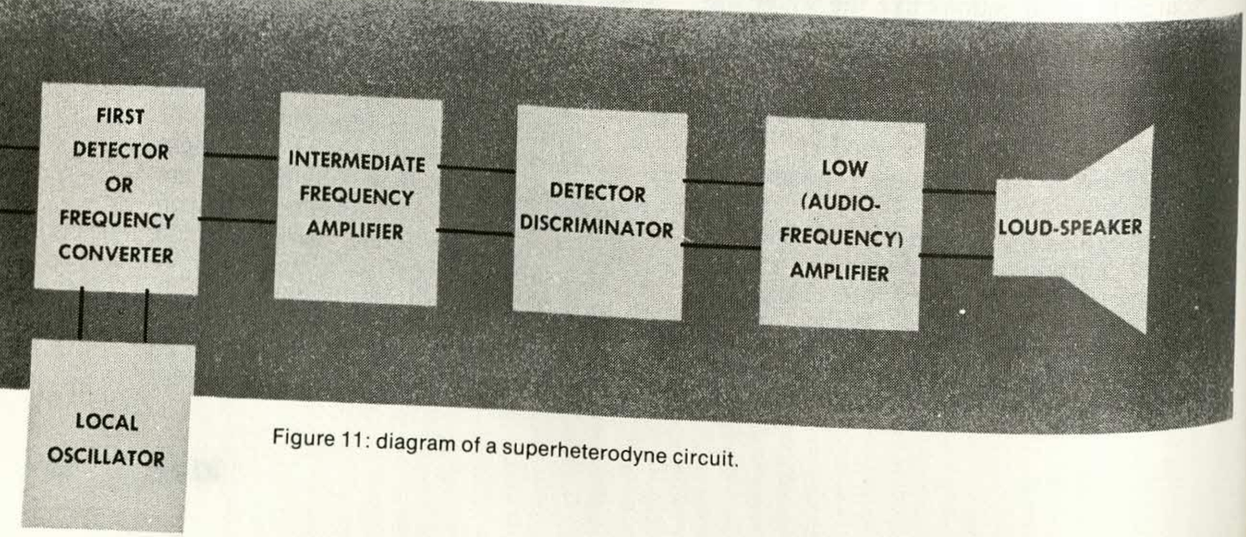

FIRST DETECTOR OR FREQUENCY CONVERTER
INTERMEDIATE FREQUENCY AMPLIFIER
DETECTOR DISCRIMINATOR
LOW (AUDIO-FREQUENCY) AMPLIFIER
LOUD-SPEAKER
LOCAL OSCILLATOR

Figure 11: diagram of a superheterodyne circuit.

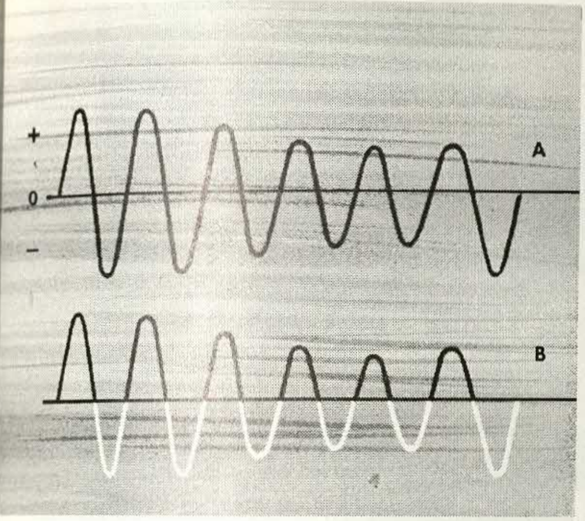


Figure 12: diagram shows how radio-frequency signal is transformed. *A* is the original alternating current. *B*, the negative pulses of current are eliminated by detector circuit.

called the *intermediate frequency*. The point is that the frequency of the local oscillator is changed with each carrier so that every signal coming in produces exactly the same intermediate frequency. With just one frequency to deal with, an intermediate-frequency amplifier (Figure 11) that has extremely high strengthening power can be built in the set. It is said to have *high gain*.

This is the *superheterodyne* principle used in the vast majority of radio and television receivers. It was invented by Howard Armstrong, an American who was also the developer of FM radio. An example or two may help make this rather complicated system clear.

If the intermediate frequency used in the set is 450 kilohertz, and the signal tuned in is 1,000 kHz (near the middle of the AM band), the local oscillator in the set will be tuned automatically to 550 kHz, so the difference will be the desired 450 kHz. If the receiver is returned to 800 kHz, the local oscillator is automatically retuned to 350 kHz, again leaving a difference of 450 kHz. An intermediate-frequency amplifier for just one frequency can also be very effective at rejecting other stations that are a little off the frequency tuned in. This *selectivity* is an important aspect of the circuit.

The intermediate frequency is still carrying the program, and this goes to a *detector*, a circuit that converts the rapid AC alternations of the carrier to the required fluctuating DC.

In the early days of radio, this was done by means of a crystal detector circuit. It was given the name ''detector'' because, by changing alternating current to direct current, it made it possible to detect radio waves.

Crystals of galena, which is a compound of lead and sulfur, were used for this purpose. The galena crystal was capable of acting like an electrical valve. It permitted the flow of electrons in one direction only. The alternating current fed to this crystal would pass through it, therefore, on one half-cycle and would stop flowing on the following half-cycle.

Figure 12 shows how the current would be transformed. In *A* we see the original alternating current, with its hills and valleys—one set of hills and valleys representing the positive pulses; the other set the negative pulses. In *B*, the negative pulses have been eliminated. The positive ones follow each other so closely that the effect is that of a direct current—a current with a definite fluctuating pattern, reproducing the original pattern sent out from the microphone.

The output of a crystal detector circuit, then, is a pulsating direct current—a current flowing in one direction and periodically changing strength. In early crystal sets a thin wire was set in contact with a sensitive spot on the crystal, where the valvular action was the strongest. The wire was known as the cat whisker.

The crystal detector was replaced by vacuum-tube detectors and then by transistors. Like crystal detectors, they change the alternating current flowing through the aerial and the tuning circuit into direct fluctuating current. The fluctuations follow the same pattern as in the microphone. We now have an audio-frequency current—one in which the frequency of the fluctuations will be the same as that of the sound waves produced at the site of the broadcast. Then, usually with some more amplification (called *audio amplification*), the DC reaches the final stage—the loudspeaker or headphones.

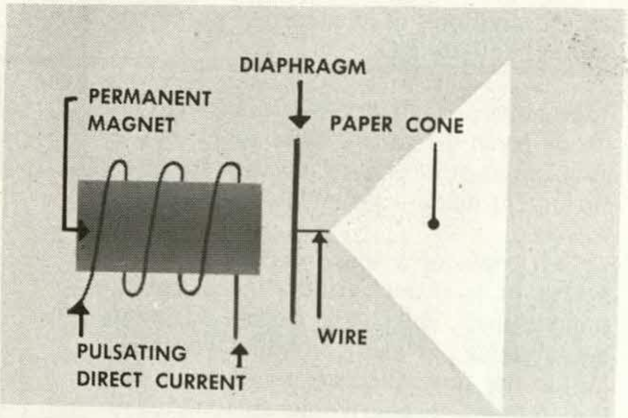


Figure 13: diagram showing the workings of a simple magnetic speaker.

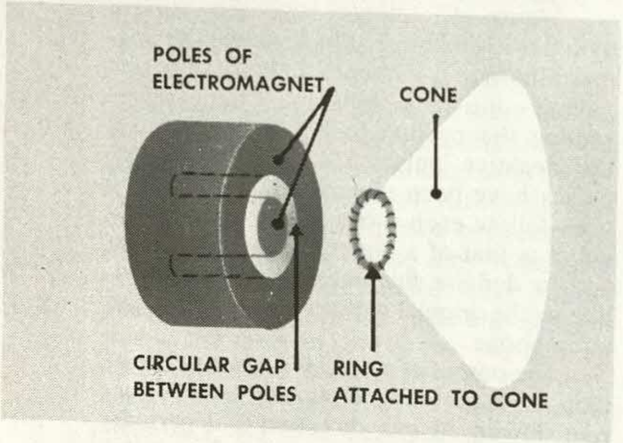


Figure 14: diagram of a dynamic speaker showing the circular gap and ring of the speaker.

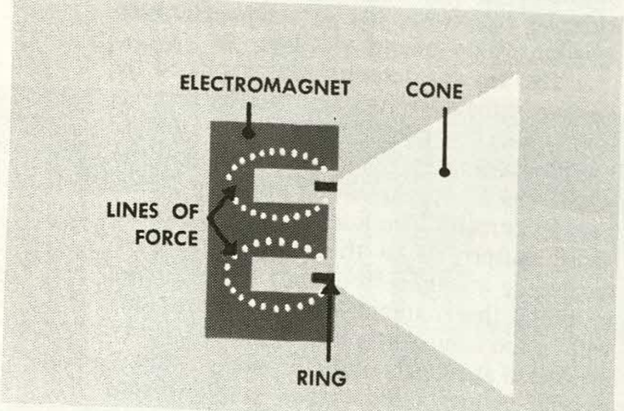


Figure 15: dynamic speaker in cross section. Ring of speaker is now shown in position in the gap between the poles of the electromagnet.

TRANSDUCTION—FROM ELECTRICITY TO SOUND

We all know that a loudspeaker produces sound that is a very close copy of the sound that started out in the radio studio, or in some earlier source such as the recording studio. Figure 13 shows how the simple magnetic speaker works. The so-called *dynamic speaker* (Figures 14 and 15) has a strong magnet with a circular gap in it, a diaphragm connected to a large paper cone that is free to vibrate, and a ring of wire—the *voice coil*—attached to the cone and projecting into the gap in the magnet.

When the fluctuating DC from the receiver is fed through the voice coil, the interaction between the magnetic field formed around the coil and the permanent magnet in the speaker pushes the coil, and the cone with it, back and forth in vibrations in step with the original sound. The cone kicks the air off into sound waves that are a good copy of the original.

Headphones work in a similar manner. Some headphones have the coils wrapped around fixed magnets, with a flat diaphragm mounted very close, as in a telephone receiver. The strength of the magnet is varied in step with the signal fed to the coil. Some headphones are like miniature loudspeakers, with tiny voice coils attached to the diaphragms that move in and out.

Microphones, speakers, and headphones are all called *transducers*, devices that change one form of energy to another. Microphones convert the acoustic energy of sound first into the mechanical energy of the moving diaphragm, and then into the electrical energy of the signal. Speakers and phones behave in reverse—converting electrical energy to mechanical and then acoustic energy.

Radio technology is full of complex detail that could not be covered in this brief article. And it is constantly being enlarged and improved by a host of scientists and engineers working in the industry. It is one of the most forward-looking technologies, and new ways of serving the listener can be expected to appear in the future as the communications industry grows.

Boy Scouts of Canada

AMATEUR AND CB RADIO

by Don Waters, WB1CUJ

The sounds of radio are everywhere around us. Broadcasting studios in towns and cities provide us with news and music and many other kinds of programs. There is one thing about them—you can't talk back. You can call in to talk shows and speak with disc jockeys. But for the most part, ordinary radio is a one-way system of communications.

There is another, fascinating world of radio, however: amateur radio. Here people can talk directly with one another and not just listen in. Amateur radio is one of the most enjoyable and rewarding of hobbies. It is also the only hobby that is regulated by international treaty.

Amateur radio reaches around the world. There are nearly one million amateur, or "ham," radio operators, with about 300,000 of them in the United States alone and nearly as many in Japan. Radio hams can and do converse on just about any topic, subject only to being noncommercial and to speaking in good taste. Often the talk is devoted to an exchange of information about equipment, signal strength, and so on. But often it is simply a sharing of experience: families, interest, everyday events. Hams even play chess by radio.

A UNIQUE WORLD

The international ham community is unique in several ways. For one, all its members are on an equal basis so far as their hobby world is concerned. For example, a New York City ham was excited one day to hear his call answered with a voice saying "JYL—Hussein here." He suddenly realized that he was talking with King Hussein of Jordan, who is an active and enthusiastic radio amateur.

Emergency communications is another long tradition among radio amateurs. They have an organized field program to train and prepare for emergencies and be ready to swing into action when the need arises. For example, one morning early in 1976 a ham in Ohio and another in New Mexico were talking casually when another voice suddenly broke in: "Terremoto! Ayuda!" One of them fortunately understood this as Spanish for "Earthquake! Help!"—the first word to the world of the disastrous earthquake that had just struck Guatemala.

Wide World

With a more powerful setup, this ham operator in Czechoslovakia became the first non-U.S. radio amateur to contact all of California's counties.

For the next several days, help from national governments and international relief agencies was mobilized and coordinated by means of amateur radio. Short-range radio equipment was rushed to the stricken country as an emergency internal communications system. Radio amateurs in several regions went on round-the-clock status to maintain a wider relief network for the earthquake victims.

Ham public service takes less dramatic forms, as well. It keeps people in remote outposts in touch with their families, provides communications control during public events, and serves in many other ways. For all these reasons, amateur radio is given valuable space in the radio spectrum by the governments of the world.

Finally, there are no barriers of geography or language in ham radio. There is a system of radio shorthand, called *Q signals*, that means the same in every language. For example, "QTH" means home or residence location, "QRX" means "Stand by," and "QRS" means "Send more slowly." A QSL is a traditional postcard exchanged in confirmation of an on-the-air contact, and many hams accumulate hundreds of them. There are also other abbreviations. "TNX" means "Thanks," the number 73 at the end of a message means "Best regards," and—in case you want to know—the number 88 means "Love and kisses."

EQUIPMENT AND RADIO BANDS

"How much does it cost to get into amateur radio? Isn't it expensive?" This is a common question raised by people thinking about taking up the hobby. The answer may be surprising. In the United States it is entirely possible to get a license, acquire a basic station, and go on the air for less than $100. This is particularly true if the newcomer has the guidance of an old-timer in what to look for in the way of used equipment or simple kits.

Where one goes from the basics depends on how his or her amateur interests develop. In many ways it is like photography. You can run the gamut from very simple and inexpensive but effective equipment to a very elaborate station costing $100,000 or more. The average ham investment in a station over a period of years ranges from $3,000 to $5,000.

The basic equipment consists of a radio transmitter, a receiver, and an antenna. Usually the equipment is bought, but there are also do-it-yourself kits. Some hams design and build their stations entirely on their own. The station may be the corner of a room, or it may take up the entire room. Broadcasting from vehicles is also permitted. Communication may be by means of voice, radiotelegraphy (that is, Morse code), radioteletype, or even amateur television equipment.

Depending on their proficiency, hams can use up to 1,000 watts of power to send out their messages. Amateur radio is allotted several bands in the shortwave range of the radio spectrum, the same range used by ships, airplanes, police, and others. Most nations of the world have agreed on which bands amateur radio may use.

GETTING A LICENSE

The beginner license requirements are simple for anyone with the desire to be a ham radio operator. There are no age limits, and children as young as five have managed to obtain a license and run a station.

You have to learn Morse code as a

beginner, but it is not at all difficult with a few weeks of practice. International treaty agreements require this, because code is still the surest, simplest way to get a radio signal through under almost any conditions. Beginners need only be able to transmit six words in code per minute. They must also pass a very simple 20-question, multiple-choice test on radio theory and on the government-established regulations controlling amateur radio.

In the United States the Amateur Radio Service is administered by the Federal Communications Commission, which issues five classes of amateur licenses: Novice, Technical, General (the most common), Advanced, and Amateur Extra. The Novice license is issued for a two-year period and is not renewable. It was deliberately designed to make entry into amateur radio and getting on the air as easy as possible. The Novice test is conducted by mail and may be administered by any qualified ham.

With each advance in rank of license, further technical knowledge is required. There is also a slow increase in the number of words per minute that you must be able to transmit in Morse code. The last three ranks are administered at an examining office of the Federal Communications Commission. As you advance, you are permitted to use more and more transmitting power and to operate within wider portions of the amateur radio bands. The conditions that are set for hams vary from country to country.

As a ham, you have a "name" by which every other radio amateur will know you. That is, each station is assigned a call letter. An amateur radio call—for example, WB1CUJ—always consists of a one-or two-letter prefix that indicates your country. The United States is either W, K, or N. This is followed by a single numeral for your geographical region, such as 1 for New England. Two or three letters follow that represent you as an individual. You can often see these amateur call letters on automobile license plates—a privilege accorded hams in the United States and Canada.

Wide World

Citizens Band radio transceivers are simple to operate. This 40-channel model, shown with its microphone attached, is suitable for home use.

THE AMATEUR RADIO RELAY LEAGUE

Most hams agree that the easiest way to a Novice license is through one of the classes conducted by community radio clubs or with the assistance of a licensed amateur nearby. Help in locating a club or local ham—or just general information about amateur radio—is available from the American Radio Relay League, Newington, Connecticut 06111, an association of U.S. and Canadian radio amateurs. The League publishes training material, a monthly technical journal, an annual handbook, and a number of other publications on special phases of amateur radio. It also operates a headquarters station, WIAW, which transmits to hams. It maintains a Technical Information Service to answer questions from any amateur on problems relating to station equipment. It coordinates an extensive field organization for public service and other operating activities, and it represents the interests of radio amateurs with the Federal Communications Commission and other national and international government agencies. The headquarters staff of about 125 people functions under policies and directives established by a regionally elected and unpaid Board of Directors.

The ARRL was created in 1914 by Hiram Percy Maxim of Hartford, Connecticut, a noted inventor, automotive pioneer, and ardent radio amateur. Maxim saw the League as an organization to extend the very limited range of amateur radio at that time by means of a nationwide system of relays—hence the name of the organization. But he also saw a need for more—an organization to advance the long-term potential of this new avocation. Maxim's leadership guided the League until 1936. W1AW, the Maxim Memorial Station, perpetuates his call letters.

CONTESTS AND AWARDS

Amateur radio has developed its own special-interest fields. One is DX, or contact with other amateurs in distant places—the more remote the better. One of the hobby's oldest and most coveted awards is DXCC, given for verified contacts with 100 or more different countries. In amateur radio, a "country" may be England or France or Japan—or an uninhabited rock in the middle of an ocean.

To indicate just how compulsive "chasing DX" can be, there have been a number of "DXpeditions" in which a ham or small group of hams, either self-financed or financed by contributions, journey to a far-off spot where amateur radio normally does not exist. Such places are usually isolated islands or rock outcroppings, and just getting there can be a difficult and tedious process. Once there, the DXpeditioners set up portable station equipment and go on the air, often around the clock. The resulting pileup of DXers anxious to get another rare QSL can be almost unbelievable.

Amateur radio rigs can be set up in a corner of a room. This operator, wife of the U.S. ambassador to Venezuela in 1967, spent long hours relaying emergency calls when an earthquake struck there.

Cobra Communications Product Group, Dynascan Corporation

There are also a number of regular contest events in which large numbers of amateurs participate. One of the most popular and certainly the most famous is Field Day, held on a weekend in June every year. Groups of hams, usually from local clubs, set up portably-powered stations at camp sites or on hilltops and try to log more contacts than any other group. The event started years ago as a training exercise for emergencies and has become an event thousands of amateurs look forward to every year.

For newcomers to the amateur ranks, there is even an annual Novice Roundup. Among the much-sought-after awards in amateur radio are WAS, or Worked All States, one of the first certificates acquired by many new hams; WAC, or Worked All Continents; and Code Proficiency awards at various speed levels.

DEVELOPMENTS IN HAM RADIO

Amateur radio is as old as radio itself, because in the beginning all operators and experimenters were amateurs. This includes Guglielmo Marconi himself, the father of wireless communications and an amateur enthusiast.

From its beginning at the turn of the century, amateur radio developed quickly. By 1912 there were so many stations that a law was passed to prevent interference between them. Private stations, including amateurs, were assigned radio bands in the shortwave region that engineers thought to be worthless. The amateurs soon proved this was not the case, sending messages over longer and longer distances. In 1923 they achieved the first two-way communication by shortwave across the Atlantic Ocean.

Through the years, amateurs have continued to be experimenters. For example, in 1960, hams in California bounced their signals off the moon for the first time, the message being received in Finland. An electronics professor in New Jersey who is also a radio ham succeeded in "working all continents" by moonbounce, simply by using his own large, backyard antenna.

In 1961 a group of California hams, mostly employed in the aerospace industry, designed and put together a small communications satellite, and persuaded the Air Force to launch it as a hitchhiker with other space hardware. They called their satellite Oscar, for *O*rbiting *S*atellite *C*arrying *A*mateur *R*adio. It was the first nongovernment, nonmilitary satellite. For a few weeks it emitted the Morse code signal for "HI". In the years since, hams have designed and produced an increasingly sophisticated and useful series of Oscars. One was built with components produced by Australian, German, Canadian, Japanese, and U.S. amateurs. They have all been launched by the U.S. National Aeronautics and Space Administration. A cooperative educational program has been developed, based on Oscar, in which local demonstrations of space communication take place right in the classroom. Specially prepared curriculum material is available to teachers to help relate the Oscar experience to mathematics, physics, geography, and even the social sciences.

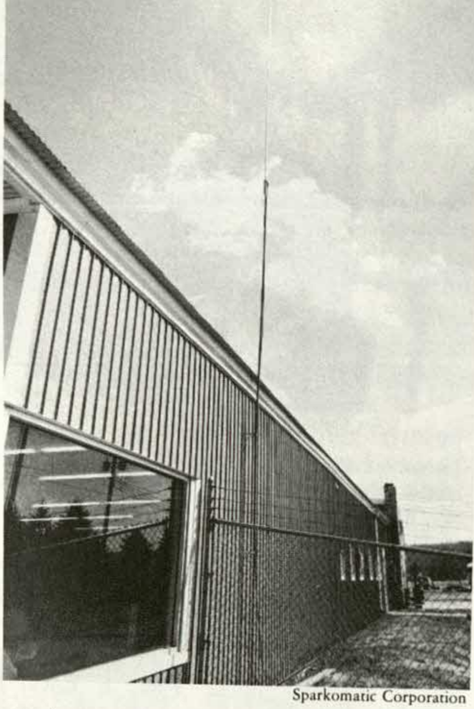
Cobra Communications Product Group, Dynascan Corporation

CB home stations can be used to communicate with people who are traveling in vehicles. Licenses are easy to obtain and regulations are simple.

One popular aspect of amateur radio today is two meter FM, a very high frequency band with short, line-of-sight range. The equipment is small and compact, and hams use it mostly in their automobiles. The range is extended by means of "repeaters." These are devices for receiving and retransmitting a signal. Repeaters are usually operated by local clubs and located atop hills or tall buildings. There are now a couple of thousand repeaters in every section of the United States. They are listed in a directory so that traveling hams can find out how to gain acess to one almost anywhere for local communication.

Sparkomatic Corporation

Use of CB by U.S. truck drivers in meeting the fuel shortage of 1973 caught the public's imagination and contributed to a rise in CB sales at that time. Range of sets on vehicles is usually limited to about 25 kilometers.



Sparkomatic Corporation

Home antennas can rise no higher than 18 meters or else 6 meters higher than the building does.

CITIZENS BAND RADIO

Another form of noncommercial radio is also very popular today: Citizens Band, or CB, radio. It is different from amateur radio in several ways. It occupies a very small portion of the radio spectrum, centered in the 27-megahertz region. It is limited to an operating power of four watts and is short-range only. Typically, a home CB station can transmit no farther than 50 kilometers, and a CB unit in a vehicle no farther than about 25 kilometers, although this varies with local conditions.

On the other hand, CB sets are lightweight and inexpensive. They provide a handy system for two-way communications between people at home and on the road. Truckers use them constantly to talk with other truckers. Having a CB set is like having a wireless telephone of short to medium range at your service. However, the communication usually has to be line-of-sight—the radio signals are not likely to get past any major obstructions. Sometimes the signals "skip" along the lower layer of the earth's ionosphere for greater distances, but purposely making use of this phenomenon is illegal.

Basic equipment includes a combined transmitter and receiver, or transceiver; an antenna; and some coaxial cable. The antenna for a home installation cannot be higher than 18 meters above the ground, or else six meters higher than the station's building. The CB set is crystal-tuned. That is, the crystal in the set is designed to vibrate at certain set frequencies. Thus a CB set is tuned by switching from channel to channel, as in a television set, rather than dialing, as on radio sets. At present 40 CB channels are available.

Getting a CB license is simple. You must have a mailing address and be at least 18 years old, although once you have your set you can let younger people use it under your supervision. You also have to obey a few simple rules such as not using "skip," not swearing on the air, and breaking off conversations for one minute if they last longer than five minutes. Your call sign will consist of a three-or four-letter prefix followed by a four-digit number—for example, KGA 1234.

CB radio began in the 1940s with the creation of the Citizens Radio Service for the regulation of radio-controlled appliances, including mobile radio telephones. Citizens Radio Service occupies a higher frequency band than does the present CB radio. The latter was made a special class of the Service and moved to its present band in 1958. Thereafter CB radio use grew slowly until the early 1970s. At that time a fuel crisis developed in the United States, and truckers found CB a convienent means of finding fuel sources when regular stops ran dry. Their use of CB, and the colorful lingo they developed in their communications, caught the public imagination. Sales of CB sets rose rapidly, and in 1975 the Federal Communications Commission lifted its prohibition on the hobby use of CB radio.

For those who have experienced the taste of personal two-way radio communication through CB, there is an even more interesting world in store in amateur radio. Much more than a pleasant hobby, it offers the satisfaction of membership in a community that reaches around the world.

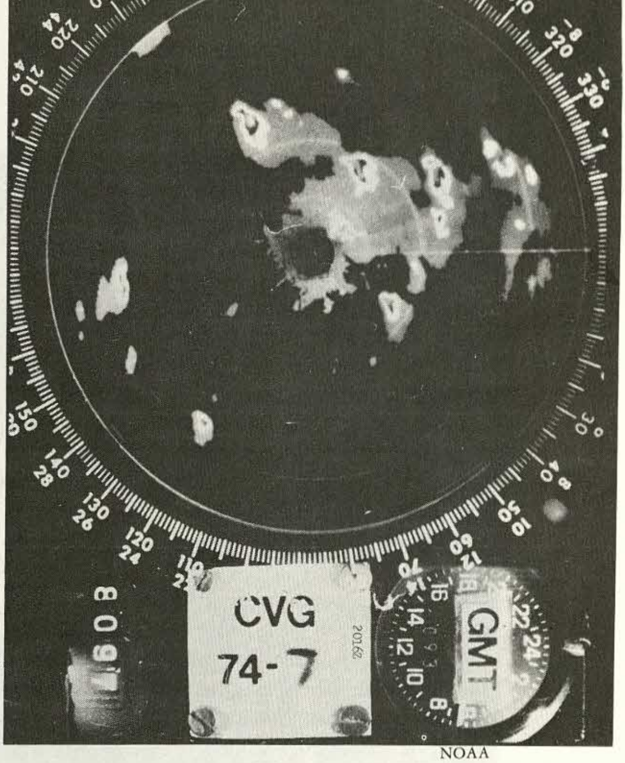
RADAR

by Irving H. Page

When a mariner is approaching a rocky coast at night, he sometimes sets off a whistle blast and ticks off the seconds until he hears the faint echo of the blast come back from shore. By noting the number of seconds that have elapsed, he can determine roughly how far off the coast is. This crude method of detection is based on the fact that sound travels in air at the rate of roughly 330 meters per second. Our mariner knows that the sound waves generated by the whistle blast have to go out to the shore and back. Hence the actual distance to the shore is 165 meters for every second of delay from the time the original blast was emitted to the time when the echo was received. A cliff 1,650 meters away would give back an echo about 10 seconds after the setting off of the blast.

Like sound waves, radio waves have echoes, reflected from metals, wood, glass, plastics, and other objects. The reflected radio energy will be scattered in many different directions, including the direction from which the radio signals originally emanated. This phenomenon has been put to use in the device called *radar* (from *RA*dio *D*etection *A*nd *R*anging).

A radar transmits radio-frequency energy. This is focused into a beam, which is made to scan a wide area. Reflections, or echoes, from a target in this area then make their way to a radio receiver. Since radio waves travel at a constant speed—about 300,000 kilometers per second—the distance of the target can be determined by measuring the time that has elapsed from the transmission of the radio energy to the reception of the echo from the target. The latter's position can be indicated by noting the position of the beam that yields the strongest echoes. In some cases, one can also calculate the velocity of the target.



NOAA

The intense white areas are tornadoes as they appear on a radar screen. Weather forecasting relies a great deal on radar views of cloud patterns.

EARLY DEVELOPMENT

The history of radar goes back many years. As early as 1887, the German physicist Heinrich R. Hertz generated short radio waves with electric sparks and showed that they could be bounced off flat metal plates. Almost twenty years later, another German physicist, Christian Hülsmeyer, patented a system in which radio-wave echoes were to be used to detect marine hazards.

The first important breakthrough in the development of radar came in connection with the study of the ionosphere, an electrified medium existing above the earth and reflecting or refracting radio waves. Arthur E. Kennelly and Oliver Heaviside had theorized in the early 1900s that such a medium existed. In the early 1920s, A. H. Taylor and Leo C. Young, of the U.S. Naval Research Laboratory, confirmed the existence of the medium. In order to further their researches on the ionosphere, they collaborated with Gregory Breit and Merle A. Tuve in the construction of a radar device, called a *pulse-echo radio*. It enabled these scientists to measure directly the height of the ionosphere. To do so, they first sent out a pulse of radio energy. Then they measured the time required for this pulse to go up to the reflecting ionosphere and to come back to a receiver on the ground.

In 1922, Taylor and Young had noted the interference effect of a boat passing between their high-frequency transmitter and receiver. They had recognized the possibilities of radio echoes in the detection of remote objects. In the 1930s, they noted that aircraft passing through the radio paths between transmitter and receiver also caused interference effects. In 1934, Robert M. Page, a radio physicist at the U.S. Naval Research Laboratory, was assigned the task of building and demonstrating a device that could bounce radio waves off aircraft and detect their presence. In a few months, his assemblage of laboratory gear detected a faint "squiggle" caused by an airplane taking off from the Naval Air Station, nearly two kilometers away. Thus modern pulse radar was born.

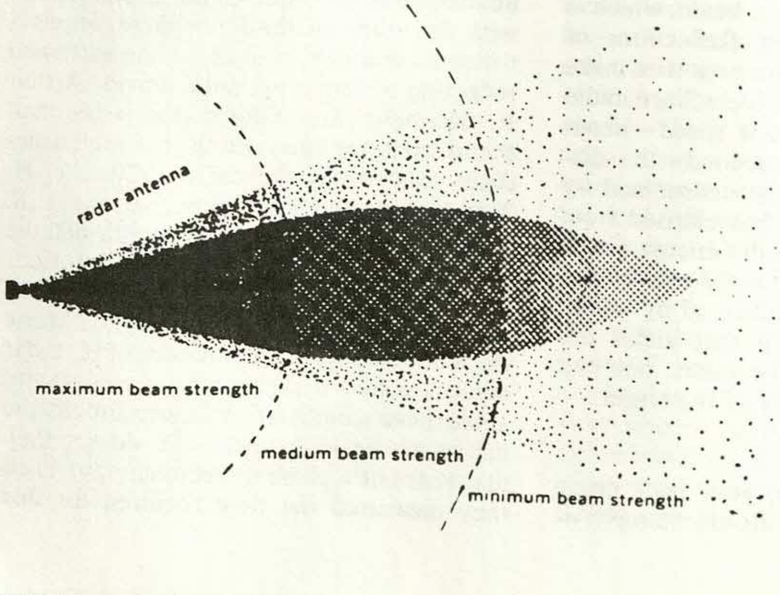
Other physicists—U.S., British, German, and French—worked on the problem of radar in the 1930s. In Great Britain, Robert A. Watson-Watt conceived of a system for detecting airplanes and determining their positions by radar. The English formed a committee in 1935 to develop Watson-Watt's system. A chain of radar stations was established in the following years along the eastern coast of Great Britain.

Since that time, developments in radar have come thick and fast, and this device has had many applications.

HOW IT WORKS

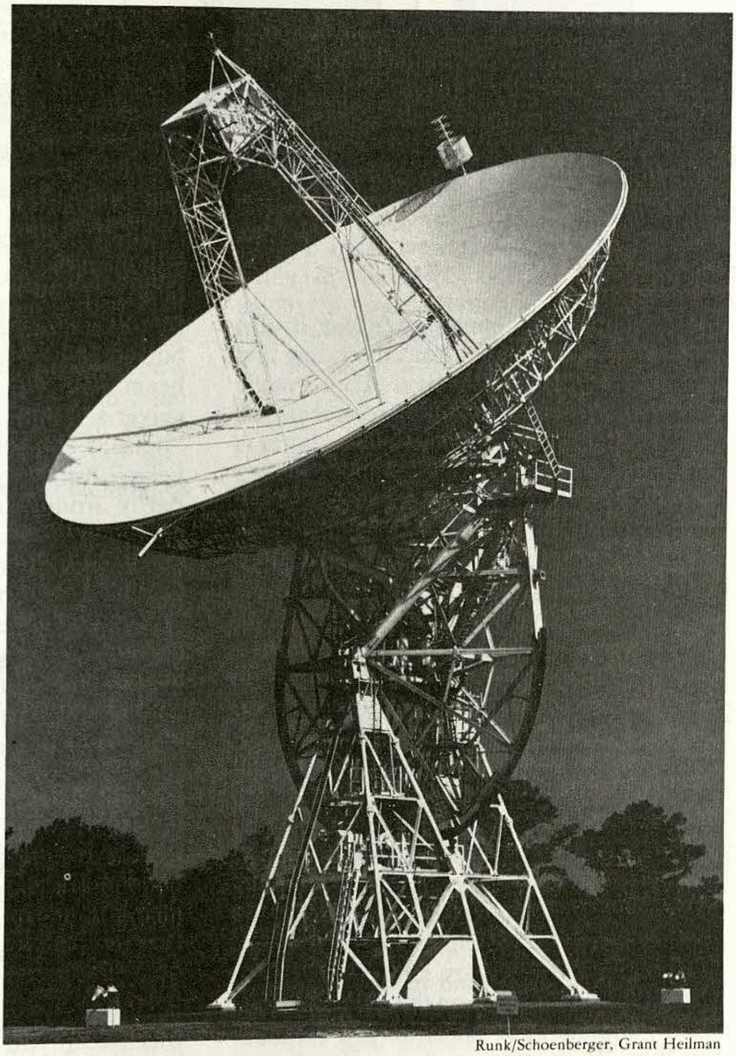
There are two basic types of radar—continuous wave, or *c-w*, and pulsed radar. The *continuous-wave radar* transmits radio waves continuously, as the name indicates. In the tracking of moving targets, the radio signal that is emitted has a constant frequency. The frequency of the returning echo will depend upon the speed and the direction of the object that is being tracked. This is an example of the Doppler effect. In fact, the continuous-wave radar is sometimes called the Doppler radar. A part of the signal is fed, as it is transmitted, into the receiver. When the reflected signal arrives at the receiver, the differences in frequency between transmitted and reflected signals are continuously measured and are displayed or recorded. The operator can tell whether the object is moving toward him or away from him and what its velocity is.

For stationary targets, the transmitting frequency is varied regularly and continuously. The frequencies of the transmitted signal and of the target echo will differ by an amount proportional to (1) the rate of change of the transmitter frequency and (2) the time taken by the transmitted signal to reach the target and to return.



Radar beam showing areas of comparative strength. The strongest zones are in the darkest areas.

Dish-shaped radar antenna. Radar antennas are modified to send and receive signals.



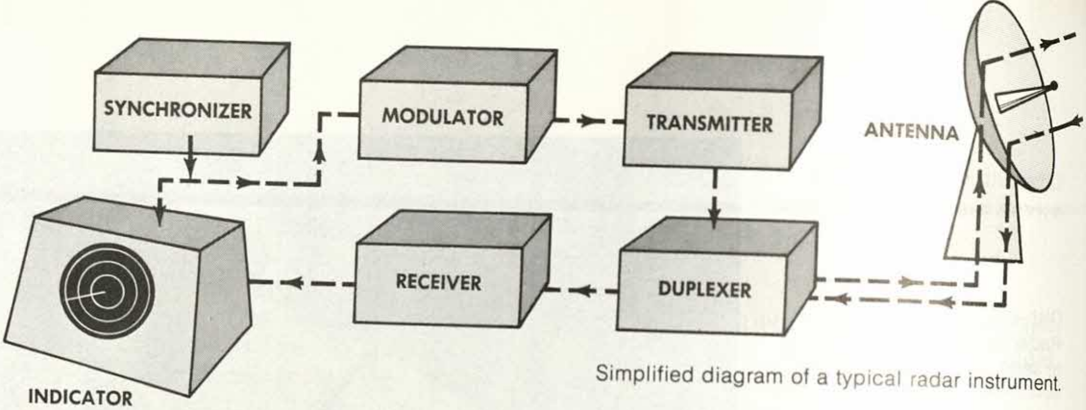
Runk/Schoenberger, Grant Heilman

The *pulsed radar* is used far more widely than the continuous-wave variety. It transmits radio-frequency energy in short bursts, or pulses, emitted at the rate of from a few hundred to many thousands per second. After each pulse, there is a listening period, during which echoes from the target may be received with no interference from the radar's transmitter.

Each pulsed radar generally has seven basic elements—the synchronizer, the modulator, the transmitter, the duplexer, the antenna, the receiver, and the indicator. The arrangement of these elements is illustrated in the diagram on the facing page.

The *synchronizer,* an electronic oscillator, generates low-power pulses, setting the frequency of the pulses to be beamed later by the antenna. The *modulator* contains an electric-energy storage device. This is discharged to produce a high-power pulse every time a low-power pulse is received from the synchronizer. The transmitter, a high-frequency oscillator, converts the direct-current energy from the modulator into pulses of radio-frequency energy. These pulses are fed into an antenna, which beams them out into space.

The *antenna* serves a twofold purpose.



Simplified diagram of a typical radar instrument.

Not only does it emit pulses but it also picks up return echoes from the target and sends them on to the receiver. This is made possible by the *duplexer*. It disconnects the receiver from the antenna while the latter is transmitting. After the pulse has been transmitted, the duplexer disconnects the transmitter from the antenna, so that the radio echoes may be channeled to the receiver.

There are various types of antennas. The most familiar one is a parabolic dish-shaped device, which keeps rotating while it is in operation. The dish is often cut away so as to send out a beam of a desired width, broader or narrower. Sometimes two antennas are set side by side, one sending out a broad beam, the other a pencil-thin beam. As an antenna rotates, generally many times a second, it scans a wide area.

The faint radio signals picked up from a target by the antenna are fed to the receiver, where they are amplified, so that they may be displayed on the indicator. The basic component of the latter is a cathode-ray tube. It is quite similar to the picture tube of a television receiver, though sometimes smaller. As in the case of the television picture tube, the inner face of the radar cathode-ray tube has an electroluminescent coating that glows when struck by a beam of electrons. In this way it produces the radar display on the outer face of the tube—the *radar screen* or *scope,* as it is often called.

Pulsed-radar information may be displayed in various ways. The *A-display,* or *A-scope,* is used to show the *range,* or distance, of the target. In this device, the cathode-ray beam produces a trace of light running horizontally across the face of the tube from the viewer's left to his right. The light trace actually moves back and forth, but it is not visible on the return sweep. The beam is deflected vertically by the receiver's output, which includes random "noise," as well as the radio echoes received from targets. This noise is derived partly from effects originating in the receiver itself, and partly from unwanted targets. The targets produce wider deflections from the horizontal. These variations can be interpreted so as to indicate the range of the targets. In the *B-display,* or *B-scope,* the display shows both range and direction, as indicated on a screen scale laid out in squares. The *C-scope* does not indicate range. It displays direction and elevation.

By far the most frequently used and most familiar display device for pulsed radar, or indeed any kind of radar, is the *plan-position indicator,* or *PPI*. In this, the cathode-ray beam starts from the center of the scope as it sweeps in a straight line across the face of the tube. Its direction in this sweep will depend on the direction in which the antenna beam is pointing. Generally the beam will produce a faint glow, corresponding to "noise," on the radar screen. But, if an echo from a target appears, it will be displayed as a bright spot, called a *blip*. The target appearing on the screen as a blip may be a plane, a ship, a portion of a landmass, or a bridge. As the radar antenna keeps rotating, there will be a rapid succession of cathode-ray-beam sweeps, radiating from the central point. The beam will keep revolving around the central point of the screen, much like the second hand of a watch.

By the time the first circuit is completed, there will be a pattern of blips on the radar screen. As one circuit follows another, the blips will be reinforced, and the pattern will be retained. Slow-decaying phosphors are sometimes used in the electroluminescent coating so that the pattern may persist from one sweep to the next. The screen is marked out with a series of concentric circles—the *range markers*. These furnish a distance scale to indicate how far off the target is from the receiver (corresponding to the central point of the scope). The direction of the target is indicated by markings on an outer circle, covering a full 360° range. As the observer eyes the radar screen, he sees a map, showing the general land features and also targets on land or at sea. Special techniques are used to determine elevation.

Radar information is not always displayed on a radar screen. Sometimes it is recorded on tape or film and is then put aside for further analysis. Sometimes it is fed directly into a computer, which makes various calculations on the basis of the information provided for it.

IMPORTANT USES

Military search radar. A most vital military role of radar is the search for aircraft, missiles, or ships. Search radar serves in some elaborate systems to give warning of approaching planes or missiles. The information is then transmitted to U.S. defense centers.

Naval vessels regularly use two types of search radar. One is for surface search of ships and of obstacles to navigation. The other radar, with a much longer range, is used for air search to detect planes.

Interception radar. *Ground-controlled interception* (GCI) *radar*, based on land stations, and *ship-controlled interception* (SCI) *radar*, based on aircraft carriers, are used to direct military aircraft. Sometimes radar is installed on the interception planes themselves. This is known as *airborne interception* (AI) *radar*. Generally AI radar is used to track down planes in the dark.

Fire-control radar. This device locates targets accurately and directs gunfire or missiles against them. A group of beams or a conically scanned beam from a tracking radar picks up the target and follows it in its course. The radar measurements are fed to a computer, which calculates the previous course of the target, its present position, and where it may be expected to be when the projectile intercepts its course. This information is then relayed to guns or missiles.

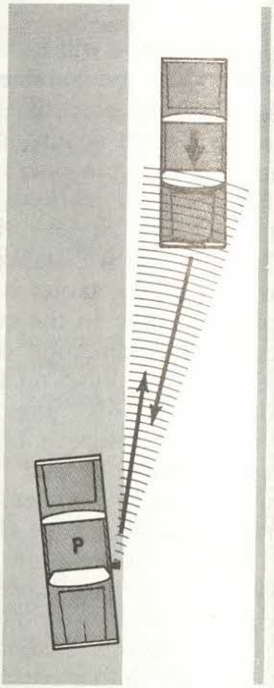
Guided-missile control. Certain missiles receive radio commands from the ground while in flight in order to direct them against a target. Both the missile and the target are tracked by radar.

Bombing radars. Modern military aircraft carry high-resolution microwave radars, which allow excellent mapping of the ground terrain in their vicinity. Such features as mountain ranges, coastlines, rivers, and cities can be seen in considerable detail.

Radar for marine safety. An important use of radar is in assuring safety at sea. All ocean liners and freighters and many other ships, including a number of pleasure craft, now carry a marine radar. A device of this sort can provide information about other ships in the vicinity, shorelines, and the positions of buoys. Many buoys now have metal reflectors, which increase the range at which the buoys can be detected by radar. Shipping is often guided in harbors by means of shore-based radar systems. Through the use of radar, modern ships can run at full speed at night and in fog and they can maneuver in harbors with heightened confidence.

The radar altimeter. The standard pressure altimeter, or altitude indicator, used on planes really measures atmospheric pressure. This pressure lessens as the altitude above sea level increases. Changes in pressure are indicated in the pressure altimeter in terms of distance units. The less the pressure, the higher the altitude reading will be. This device is quite accurate in indicating the height of the plane above sea level. However, the terrain over which the plane is flying may be at a considerable height above sea level. In such a case, the plane may be dangerously close to the ground even though an altitude reading of more than 1,000 meters appears on the altimeter of the plane.

An accurate device to indicate the ac-



Automatic Signal Division, Eastern Industries, Inc.

Above: a radar speed meter, used in motor-vehicle speed enforcement. The device consists of a spotlight-type antenna, a book-size chassis (not shown here), and a reading indicator (on top of the dashboard). The drawing at the right shows how the one-man method operates. Radio waves transmitted from the police car, P, strike the moving car and are reflected to the speed meter. If the reading indicates speeding, the police car pursues the offender and flags him down. In the two-man method, a police car with radar equipment wires to another car to intercept cars going over the speed limit.

tual distance from the ground is the *radar altimeter,* also called the *radio altimeter.* This shows the height above the ground by measuring the time delay of a radio signal that is sent out from a plane, bounced off the earth, and then received again on the plane. Such a device is accurate to within a meter or so at an altitude of a few hundred meters. The radar altimeter has even been used to measure ocean-wave profiles from planes flying over the ocean.

Air-traffic control. Traffic-control radar, installed in the control centers of airports, helps to keep tabs on the goings and comings of planes and to control the flow of traffic in the air. A radar system known as *ground-controlled approach,* or GCA, is used to bring planes safely to earth when visibility is poor. The GCA radar is located near the end of the runway. Markings on the radar screen indicate the desired glide path. The oncoming plane's course is indicated by a succession of blips which may or may not follow the markings on the radar screen. In the older GCA systems, the operator would give continued instructions to the pilot by radio so that he could get on the glide path and stay there. Once the plane was close enough to the ground so that the runway was visible, the pilot would land the plane on his own. The more advanced GCA systems make it possible to land a plane on his own. The more advanced pilot. GCA radar is now to be found at all major commercial and military airports as well as on aircraft carriers.

Automobile traffic regulation. Cars exceeding the speed limit can be detected by the radar speed meter, which is now used widely on highways and city streets. This device is a continuous-wave radar, transmitting continuously at a fixed frequency. The energy reflected from a moving car returns at a slightly different frequency to the radar because of the motion of the car. The radar measures the difference in frequency between the transmitted and reflected radiation and provides a continuous record of the vehicle's speed. If the car is going over the speed limit, the operator radios ahead to a waiting patrolman, who stops the speeder.

The same basic principle is applied in measuring by means of radar the speed and number of cars moving in both directions on a busy street. The information obtained in this way is fed automatically to a central computer. It processes this information, as well as information obtained from other sources, and controls the operation of traffic lights so as to provide the smoothest possible flow of traffic.

Weather radar. Raindrops vary in diameter from almost nothing for fog and mist to a few millimeters for a cloudburst. Radar wavelengths of three centimeters and less see all kinds of rain quite well. Hurricanes are full of rain, and its distribution is determined by the wind patterns. A three-centimeter radar shows a beautiful pattern of echoes out to 160 kilometers or more as a hurricane passes by. The "eye" of the hurricane can be located, and its intensity can be predicted. The direction taken by hurricanes is notoriously erratic, but tracking by radar provides as accurate an indication of a hurricane's future course as is now available.

The effective use of radar in weather prediction is by no means restricted to hurricanes. Rain and snow can be seen by radar in weather fronts long before they reach the area of the radar. As a result, the weatherman obtains reliable information about weather hundreds of kilometers away. He can tell many hours ahead of time when snow or rain will reach a given area and how hard the precipitation will be. New techniques in continuous-wave radar make it possible to indicate velocity distribution in storms; to measure horizontal and vertical air circulation; and to add to our knowledge of upper-level rain and hail circulation patterns.

Radar in the space program. Radar is used to track launching rockets and the space vehicles that constitute their payload. After a spacecraft—artificial satellite or space probe—is on its own, the radar beam locks onto it. It provides information to ground personnel concerning the range and velocity of the craft and makes it possible to direct it into the desired flight path. Often a space vehicle is guided in space not by ground personnel but by a self-contained inertial guidance system. This is sometimes actuated by radar beams reflected from such celestial bodies as the moon or a planet.

Kustom Signals, Inc.

Hand-held radar. These devices are used by law enforcement agencies to apprehend speeders. The system is portable and efficient.

Radar astronomy. The increasingly effective use of radar has led to the development of the branch of astronomy known as radar astronomy. Radar pulses are sent out into space. When they strike a solid body or a gaseous medium, the returning echoes provide much information about the celestial target. Thus radar signals that were bounced off the moon pinpointed details of the lunar surface long before the first close-up pictures of the surface were transmitted to earth by satellites and lunar landers. The streams of ionized gases emanating from the sun have been analyzed by radar. Radar beams have penetrated the clouds that hide the surface of Venus and have provided more accurate measurements of that planet than had hitherto been considered possible by astronomers.

Radar astronomy has proved valuable, too, in the study of meteors. When a meteorite streaks through the atmosphere, it leaves behind it a trail of ionized gas that can be detected by radar. By analyzing the radar echoes from meteor trails, observers can calculate the size, path, and velocity of the meteorites that produced these trails in the atmosphere.

Dave Maenza/FPG

A live broadcast involves planning, timing, and sophisticated equipment.

TELEVISION

by Kenneth Harwood

One of the more striking developments in the present century has been the amazing growth of television. Not available anywhere on an established commercial basis before 1948, it has struct firm roots in many countries. Nowhere has its growth been more rapid than in the United States. Thousands of millions of dollars have been invested in the television industry. The vast majority of U.S. homes have at least one television set, as do many of the homes in many other developed nations. A wide variety of programs comes in a steady stream from television studios.

Though commercial televison is a comparative newcomer in the field of communication, its beginnings go back a good many years. In fact a primitive kind of television system was designed by a U.S. inventor, C.R. Carey, as early as 1875. In Carey's system the light reflected from an object or scene would pass through a glass lens, as in a conventional photographic camera. It would fall upon a bank of photosensitive electrical cells, which formed a sort of mosaic. Each cell in the mosaic would pass an electric current proportional to the amount of light falling upon it. A wire would lead from each cell to an electric lamp in a bank or mosaic of lamps, corresponding to the mosaic of photosensitive cells.

Some of the lamps would glow brightly because strong light had fallen upon the photosensitive cells to which they were connected. Other lamps would glow feebly or not at all because the light falling upon the corresponding photocells had been so faint. A rough outline of light and dark in the original scene would be reproduced at a distance from the photocells as a result of the selective glowing of the electric lamps. An offspring of this system is still in use today. You have seen it in operation if you have ever watched the words of news bulletins parading across a mosaic of electric lamps on the outside of a newspaper building.

Of course Carey's crude television system was a far cry from those in use today. It is important to note, however, that in the Carey system (1) the image of a scene was broken up into little pieces; (2) the separate pieces of the image were transmitted; and (3) the parts of the whole image were reassembled at the point of reception. Today's television systems, too, are based on the processes of (1) breaking up the original image into little pieces; (2) transmitting the pieces; and (3) building up the image anew.

SCANNING DISK

Another important event in the development of television was the introduction of a scanning device, consisting of a perforated whirling disk. It formed part of a system of television patented by Paul Nipkow in Germany in 1884. The scanning disk was a flat, circular plate, perforated with a spiral of small holes, each hole being a little nearer the center of the disk than the one next to it. The object that was being viewed was set in front of the disk. Light from a lamp would shine on the object and be reflected through one hole at a time when the disk was rotated. One whole turn would scan all of the object.

The light that had struck the object and had passed through the holes in the disk would activate a photosensitive selenium cell behind the disk. It would create an electric current whose strength would vary with the amount of light reflected from the different areas of the scanned object. The variations in current would pass along a wire to a receiver that also contained a spinning disk. The disk in the receiver would be synchronized with the one in the camera—that is, it would be made to run at the same speed. The variations of current would be transformed in the receiver into the lights and shadows in the object that had been scanned.

Nipkow was unable to construct a satisfactory receiver, because the variations in current in his television system were quite weak. Besides, the rate of rotation was too slow to permit the disk to provide a detailed picture. Nipkow's patent lapsed because he did not have enough money to continue working upon his scanner. His contribution was important, however, because it paved the way to other, more successful, scanning systems.

Hand-held cameras make on-the-scene broadcasting possible. Shoulder and hip rests help steady the camera so that the cameraman is free to focus and adjust the lens. Battery-pack is carried on his back.

Jan Lukas, Photo Researchers

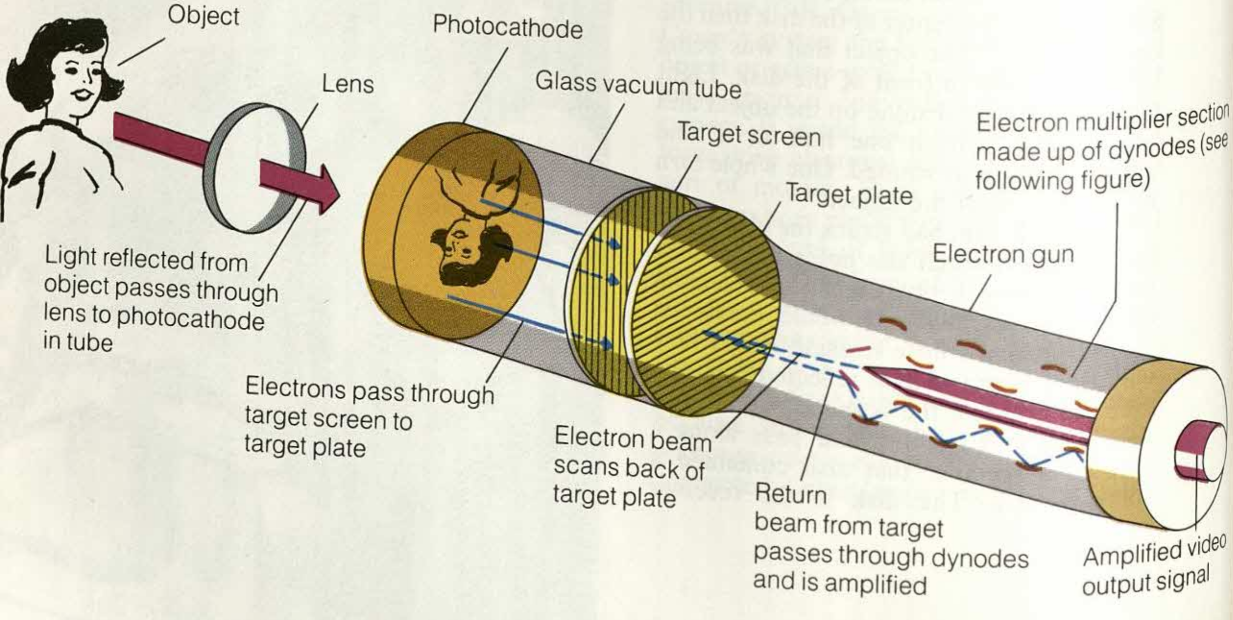
Following the pioneer efforts of Nipkow, mechanical scanning was gradually improved by various inventors. By 1926 it had been developed sufficiently so that a complete television system based on it could be demonstrated in England by John L. Baird. A few years later, the British Broadcasting System used Baird's system as the basis for a series of experimental broadcasts. However, the pictures produced by mechanical scanning were so imperfect that the future of television did not appear bright.

ELECTRONIC SCANNING

When electronic scanning was developed in the 1920s, an all-important forward step was taken. In 1923, Vladimir K. Zworykin, a Russian-American inventor, applied for a patent on the *iconoscope*, a radically new television tube incorporating the principle of electronic scanning. In this device, light reflected from an object passed through a glass lens and through the glass wall of the iconoscope tube. It fell on a mosaic made up of hundreds of thousands of silver particles, coated with selenium to make them light-sensitive. The particles were deposited on an insulating sheet of mica. When light struck these particles, electrons were emitted from them and each particle would acquire a positive electric charge proportional in strength to the amount of light falling upon it. On the back of the mosaic, a layer of conducting material was deposited to form a signal plate. This plate would acquire negative charges proportional in strength to the positive charges on the mosaic. As a physicist would put it, the positive charges on the mosaic would induce equally strong negative charges on the signal plate.

A fine beam of electrons from an electron gun within the tube would be directed to the face of the mosaic. It would scan the image being televised, in a series of horizontal lines going from top to bottom. As the beam struck a positively charged particle on the mosaic, it would neutralize it, and the corresponding negative charge on the signal plate would be released. The release of electrons from the signal plate, as the electron beam scanned the mosaic, formed an electric current that was led outside of the tube through a wire. The current would flow from the signal plate with variations that would be proportional to the elements of light and dark in the image. This variable current would be amplified and then would be transmitted to a receiving tube, called a kinescope. The kinescope also contained an electron gun. As the beam of electrons from this gun struck a specially coated surface, it would recreate the light and dark elements in the image. The resulting picture would be

The image orthicon tube.


Object
Photocathode
Lens
Glass vacuum tube
Target screen
Electron multiplier section made up of dynodes (see following figure)
Target plate
Electron gun
Light reflected from object passes through lens to photocathode in tube
Electrons pass through target screen to target plate
Electron beam scans back of target plate
Return beam from target passes through dynodes and is amplified
Amplified video output signal

much brighter and finer-textured than that produced by mechanical scanning.

Other pioneers contributed to the development of electronic television in the 1920s and 1930s, including Philo T. Farnsworth and Allen Dumont. When wholly electronic television emerged from laboratory development in the 1930s, television definitely cast off its swaddling clothes. In 1939, the National Broadcasting Company gave a series of public telecasts in an experimental station in New York and it staged television demonstrations at the New York World's Fair in the same year. By 1941, a uniform, nationwide system was agreed upon for the United States. However, commercial development of the new medium was held up during the 1940s. It was not until 1948 that bona fide commercial operation of television stations began in the United States. Other countries also made important contributions to the experimental development of television, and the commercial application of the medium spread to many countries in a short time.

In 1950, the Federal Communications Commission (FCC) of the United States approved a system of color television developed by the Columbia Broadcasting System (CBS). It was based, at the time, on a mechanical system for breaking a picture down into three primary colors. It was not compatible. That is, it could not be used to provide black-and-white pictures on conventional sets. As a result, there was widespread criticism of the system, and the FCC withdrew its approval. In 1953, the FCC officially endorsed a compatible, electronic system of color television perfected by the Radio Corporation of America (RCA). This is the system used today.

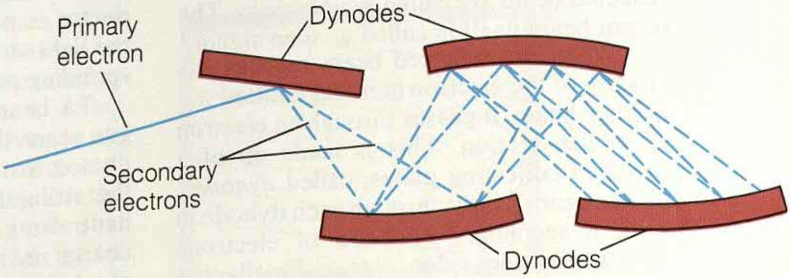
PICKUP TUBE

A television program is based on the moving images recorded by a specially designed camera—one containing the *pickup tube* in which scanning takes place. At first, the iconoscope tube was used for this purpose. It was comparatively insensitive, however, so that extremely powerful lights had to be used in television studios to produce satisfactory results. The heat generated by these lights made the studios uncomfortably hot. To provide relief, expensive air-conditioning had to be installed.

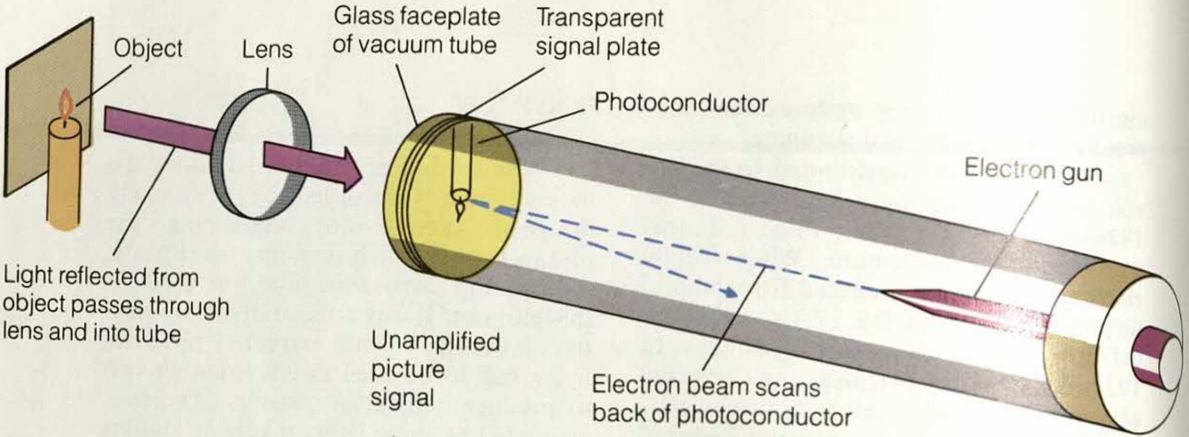
Image orthicon. The iconoscope has now been quite generally replaced by various types of improved tubes. The standard tube in the United States for television cameras is now the *image orthicon.* Since it is much more sensitive than the iconoscope, less light is required in studios than formerly. Less heat is generated and working conditions have greatly improved. The image orthicon has also resulted in cutting costs, since less light is needed and less heat has to be removed.

This is how a television camera equipped with the image orthicon tube works. Light from the subject that is being televised passes through a lens and through the transparent glass face of the image orthicon. It then strikes a thin semitransparent light-sensitive *photocathode* inside the tube. The photocathode is *photoemissive*—that is, it emits electrons when struck by light. These electrons are given off from the other side of the photocathode.

Bright parts of the image cause many electrons to be emitted from the back of the photocathode, while dark parts of the image result in little or no emission. The electrons



Close-up of the dynodes used in the image orthicon tube.


Object
Lens
Glass faceplate of vacuum tube
Transparent signal plate
Photoconductor
Electron gun
Light reflected from object passes through lens and into tube
Unamplified picture signal
Electron beam scans back of photoconductor

The vidicon tube.

coming from the photocathode are drawn to an electrically conductive target plate through the fine wire mesh of a positively charged target screen. Most of the electrons pass through the mesh and strike the front of the target, causing the emission of secondary electrons. The secondary emission is collected on the wire mesh of the target screen and is drawn away. This leaves the target plate positively charged because of the loss of electrons due to the secondary emission. The strength of the positive charge at each point on the target is proportional to the brightness of the light which struck the corresponding points on the photocathode.

A narrow beam of electrons from an electron gun is directed to the back of the conductive target plate. Upon striking a given place on the target, the beam loses electrons until the positive charge on the target is neutralized at that point. The remaining electrons in the beam are reflected from the target. As the beam scans the target, it loses more or fewer electrons, according to the amount of positive charge at each point. These variations in the reflected beam are called *modulations*. The return beam itself is called a *video signal*.

When the reflected beam reaches the vicinity of the electron gun that emitted the original beam, it passes through an electron multiplier section. This is made up of a series of collecting plates, called *dynodes*. As the beam passes through each dynode in turn, a secondary emission of electrons strengthens the video signal. Finally the greatly amplified signal is passed out of the tube.

Vidicon. The image orthicon is far more sensitive than the iconoscope and is widely used in the United States. However, for certain purposes it is at once too bulky and too costly. A smaller and cheaper television camera, called the *vidicon*, has been developed for these purposes.

When the vidicon televises a scene, light reflected from the scene enters the tube through a lens and through the tube's clear glass faceplate. On the inside surface of the faceplate is a thin film of transparent conducting material which acts as a signal plate. A thin layer of photoconductive material is deposited on the back of this signal plate. This material shows a sharp increase in electrical conductivity when it is struck by light. Light passes from the faceplate through the signal plate to the photoconductive material. Wherever this light strikes the photoconductor, it causes electrons to flow toward the signal plate, leaving a positive charge on the back of the photoconductor. The strength of the positive charge at a given point on the back of the photoconductor is proportional to the brightness of the light striking the front side at the corresponding point.

A beam of electrons from an electron gun scans the rear surface of the photoconductor, losing electrons in accordance with the strength of the positive charge that it neutralizes at each point. As a positive charge is neutralized, electrons equal in number to those that were lost from the electron beam flow from the front side of the photoconductor through the signal plate. They form a video signal which is amplified outside the vidicon tube.

The vidicon is particularly sensitive because photoconductive material produces a much stronger current of electricity than photoemissive material when a unit of light strikes it. Hence it is not necessary to put an expensive electron-multiplier section in the tube, and the glass envelope may be quite small. The vidicon tube has one disadvantage, however: there is a slight lag in response when the illumination changes. As a result, when there is much action within a live scene, the picture obtained with the tube may appear to smear slightly.

Because of its small size and comparatively low cost, the vidicon is much used in industry to televise equipment, documents, instrument readings and people. It has also been widely adopted in the broadcasting of motion-picture films, such as those so familiar in "late shows." It serves for certain types of on-the-scene televising. However, it is seldom used for televising vigorous live action, because of the slight delay in its response to changes in lighting.

SCANNING AN IMAGE

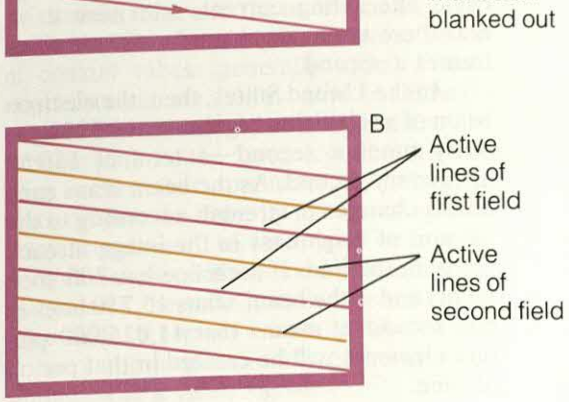
The scanning that goes on within an image orthicon or vidicon tube is the most vital part of the image-recording operation. Upon it depend the clarity and the texture of the pictures that appear on the screen of the television receiver. In the modern pickup tube, scanning takes place as the beam of electrons from the electron gun is guided by a series of electromagnets. These are wire coils, called *deflection coils*, set around the tube. They become magnets when current flows through them.

In scanning an image, the beam begins at the upper left corner. After it has moved across the first horizontal line from left to right, a *blanking signal* cancels its effect. The blanked-out beam then moves to the left and slightly downward with respect to the first line. Thus it leaves a blank line that will be used later by the beam, as we shall see. After the blanked beam reaches the left side of the picture, the blanking signal is discontinued. The active beam then begins to scan another line, moving from left to right. The processes of active scanning from left to right and of blanked retracing from right to left continue until the beam reaches the bottom of the picture. It has now completed a half-picture, also called a *field*.

To produce the second half of the picture—the second field—the beam returns to the top. It now begins to interlace the lines of the second field between the lines of the first. It scans actively from left to right and is blanked out as it moves leftward. When it comes to the bottom of the image, a complete picture, or *frame*, consisting of two interlaced fields, has been created. An entirely new frame is then begun from the upper left corner of the picture.

The total number of lines in a frame varies in different parts of the world. In the United States there are 525 lines for every

In scanning, the electron beam begins at the upper left-hand corner and traces a line from left to right (*A*). Then the beam is blanked out while it retraces, so that it can begin a second line. This leaves a blank line, which will be used later by the beam (*B*). After the active lines of one field have been traced, the active lines of a second field are interlaced between those of the first, thus forming one full frame.


A
Active line traced by beam
Retracing with beam blanked out
B
Active lines of first field
Active lines of second field

frame. Each half-picture, or field, consists of 262½ lines. In the television systems of most European countries there are 625 lines per frame, and elsewhere there are still other scanning standards. The more lines, the greater the detail in a given picture. Actually, however, the eye sees almost no difference between an image of 525 lines and one, say, of 625 lines.

ILLUSION OF MOTION

Each frame really represents a still picture of the scene in front of it. In the United States, thirty such pictures are taken every second. These still pictures create the illusion of continuous motion when they are reproduced in a television receiver. This is because of persistence of vision—that is, because the eye retains a visual image of an object for a fraction of a second after the object is no longer visible. Because one frame follows the previous one so quickly, persistence of vision lasts long enough to bridge the gap between one frame and the next.

The motion-picture camera, too, takes a number of still pictures of the scene in front of it. It takes twenty-four frames a second, and these twenty-four changes of picture suffice to give the human eye the impression of movement in a scene. A thirty-frame-per-second standard has been chosen for television in the United States in order to adapt it to the number of hertz—that is, sixty—of alternating current in that country. One television frame is created for each two cycles of electricity. Because households in Europe use fifty-cycle alternating current, television cameras there are made to produce twenty-five frames a second.

In the United States, then, the electron beam of a television camera scans 525 lines thirty times a second—a total of 15,750 lines every second. As the beam scans each line, it changes in strength according to the amount of brightness in the image at each point on the line. If each line has 700 such points and if the beam scans 15,750 lines in one second, it means that 11,025,000 picture elements will be created in that period of time.

TELEVISION STUDIO

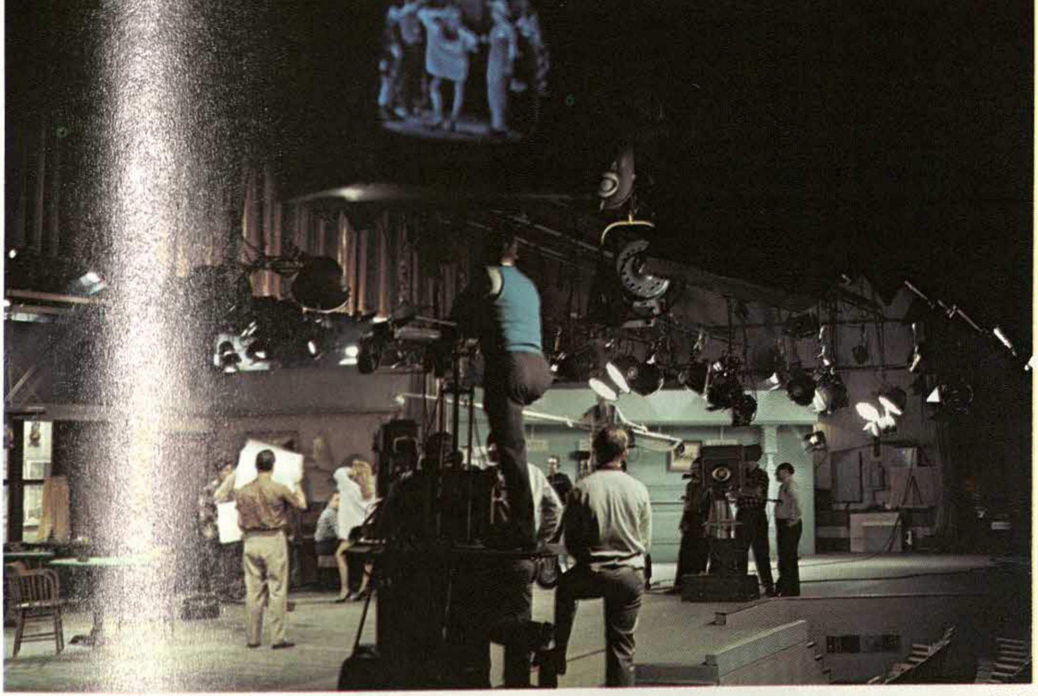
In the typical television studio, two or more cameras with pickup tubes are used for live pickup. The cameras may also be used on location away from the studio. Each camera has revolving turrets, which bring different lenses into position, so that different shots, ranging from long-distance to close-up, may be obtained. Special zoom-type lenses make it possible to change the desired focus while the picture is on the air. All the cameras that are used to record a scene operate continuously. The pictures that they take are shown on different *monitors* or television-receiver screens, in the control room. The director selects the particular picture that is to go on the air at a particular time. He switches to other pictures as he deems best. Many different effects, such as superimposing one picture on another, upside down pictures, gradual fading, and so on, can be produced.

BROADCASTING SOUND

The sound that accompanies the pictures in television is handled by different equipment—microphones, amplifiers, microphone volume controls, and so on. As the sound waves are recorded in this way, they are transformed into varying electric current—the audio signal—which will be transmitted together with the video signal. There may be a variety of sound sources: those originating in the studio or on location and recorded by means of microphones; the voice of an announcer speaking into a microphone in his booth; disk recordings; tape recordings; and so on.

ACCESSORY SIGNALS

Picture information by itself will not make the beam of electrons in the picture tube of the television receiver at home duplicate the actions of the beam in the camera tube. Other information must be added to the video signal in order to make the beam in the picture tube of the receiver scan from left to right at the proper rate; blank out the beam as it moves leftward to begin a new line; begin each new line at the correct time and place; begin each field correctly; and begin each frame properly. Ac-



F.P.G.

Elaborate sets can be built under studio lights. At one time, the lighting set-up needed for broadcasting was very uncomfortable to the cast and crew members. But today's modern cameras require less light.

cessory signals are added to the picture information for the purpose of doing all these things. Picture information and accessory signals together make up the complete video signal.

Blanking pulses in the video signal cause the electron beam of the television receiver tube to be blanked out as the beam moves from the end of one line to the beginning of the next line; from the end of one field to the beginning of the next field; and from the end of one frame to the beginning of the next frame. *Synchronizing pulses* keep the beam in the receiver tube in step with the beam in the camera tube. *Equalizing pulses* act like the ticking of a clock to assure accurate timing of the synchronizing pulses. *Driving pulses* time the action of the camera tube to allow for the time it takes for the video signal to go from camera tube to receiver picture tube.

TRANSMISSION OF VIDEO AND AUDIO

Some video and audio signals are sent by wire directly to the television receiver without going out over the air. The picture tube and the speaker in the receiver transform the electric energy of the video and audio signals into light that you can see and sound that you can hear.

More often, however, the video and audio signals are sent to a transmitter, which changes them into radio waves. These waves are then sent out over the air and are intercepted by home antennas.

Coaxial cables. If the distance from television studio to transmitter is short, the video and audio signals may be sent by wire. Where the signals must be sent over long distances, other arrangements are necessary. This happens, for example, when two television stations at a great distance from one another broadcast the same program at the same time—a program originating at one of these stations. The video and audio signals may be sent out from the originating station to the other one by *coaxial cable*. The coaxial cable contains several coaxial tubes (generally eight). These copper tubes are hollow and each has a copper wire running down its center. The tubular part is the outer conductor. The wire is the inner conductor. It is held in place within the tube by means of spaced insulating discs. The inner and outer conductors have a common axis, or center, and that is why the tube is called coaxial. The large surface area of a coaxial tube is able to carry the large amounts of information contained in a video signal.

The coaxial cable weighs less and is cheaper to make than a large solid wire of comparable size. The television signal carried over the cable is strengthened in the amplifiers of repeater stations at intervals of about 13 kilometers. The cable is buried in the ground to protect it from storms, fires, falling trees, and other aboveground dangers.

Microwave relays. Television signals may also be transmitted over long distances by means of a series of *microwave relay towers.* First a microwave transmitter changes the electrical video and audio signals into a microwave signal. Microwaves are very short radio waves. These kinds of radio waves are not received by television sets in homes.

The newly produced microwave signal goes to the top of a tower. Here a horn-shaped or dish-shaped antenna makes it into a narrow beam. It then directs the beam to a receiving antenna of similar shape on the tower of the next relay station, perhaps 50 kilometers away. In the relay station, the radio signal is automatically amplified and directed through a transmitting horn or dish to the next tower in the series. One television program may pass through more than a hundred relay towers on its way to its destination. When it arrives in a television broadcasting station, the microwave signal is changed from radio energy back to the electrical energy of the video and audio signals. The broadcasting transmitter then changes these electrical signals into radio signals that may be received by the ordinary television set in a home. Microwave relay systems have replaced coaxial cables in long-distance transmission of video signals.

In a control room, a crew member decides what image to broadcast. Several cameras send images to his booth; he can switch images instantaneously.

O.R.T.F.

When a very short radio wave such as a microwave is directed skyward, almost all of its energy passes out into space. A little of the signal, however, is bent back toward the earth. The weak signal is then scattered forward beyond the transmitter's horizon. The signal may be received by a large radio antenna having a strong amplifier. Microwaves may be transmitted in this way from one station to another, perhaps several hundred kilometers from the first. This type of transmission is called *forward-scatter* or *tropospheric-scatter transmission.* It is so called because the microwave signals are scattered into the troposphere, the part of the atmosphere that extends from the earth's surface upward to a distance of 10 kilometers or so. As a matter of fact, even an ordinary television broadcast signal, hundreds of kilometers from the transmitter, may be received on rare occasions because of unusual tropospheric scatter. Two tropospheric-scatter stations several hundred kilometers apart can do the work of many microwave relay stations that would be needed to span the same distance. Tropospheric-scatter transmission is especially useful in passing expanses of water which are wider than the reach between two microwave stations.

Video signals that have been turned into microwaves may be transmitted over particularly long distances by communication satellites.

In the near future, signal transmission may be via laser beam.

RECORDING SIGNALS

Video signals may be recorded by video tape for future use.

Video-tape recorders make a record of the varied magnetic patterns that video signals leave on a strip of plastic tape which is coated with fine particles of iron oxide. Video-tape recorders record and play back both sound and picture. Copies can be made of video tape by playing the recordings through one machine to other recorders, each of which produces a tape copy. Tapes are used for prerecording programs, for delayed program transmission, for reruns of programs, and so on. A video-tape recorder is called a VTR for short.

THE BROADCASTING OF TELEVISION PROGRAMS

The video signal, in the form of electric energy, has now arrived at the television broadcasting station, from which it will be sent over the air. The transmitter consists of two basic parts. One of these turns the electrical video signal into an AM (amplitude-modulated) radio signal. At the same time, the other part of the transmitter changes the audio signal into an FM (frequency-modulated) radio signal. The AM radio signal, representing the picture, and the FM radio signal, representing the sound, come together in a device called the *diplexer*. This combines the two signals and sends them up the broadcasting antenna. The latter increases the strength of the radio signals by concentrating them in a horizonal plane as they pass out of the antenna on their way through space to home television receivers. The gain in strength of the signals in passing through the antenna may range from tenfold to fortyfold.

Invisible and inaudible, the radio signals of a television broadcast travel with the speed of light, some 300,000 kilometers per second, vibrating to and fro millions of times during that brief period of time. Each double vibration makes up a cylce, and the number of hertz, or cycles per second, is called the *frequency*.

Photair

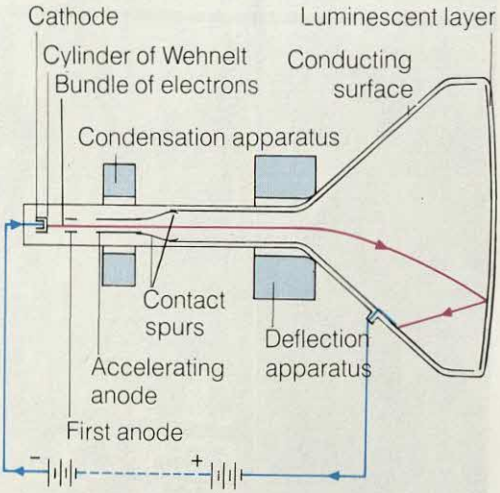
A transmitter in one of France's mountainous regions. Television signals can be relayed electronically, by microwave, and, maybe soon, by laser.

Radio signals for television have a frequency of from 54,000,000 hertz, or 54 *megahertz* to 890,000,000 hertz, or 890 megahertz, depending on the channel that has been assigned to them.

Radio signals in television channels 2 to 13 have frequencies between 54 megahertz and 216 megahertz. Since such signals vibrate at very high frequencies, they are called *VHF*, or "very high frequency," signals. Signals in channels 14 through 83 have frequencies of between 470 megahertz and 890 megahertz a second. They are called "ultra high frequency," or *UHF*, signals.

Both VHF and UHF signals act much like light, not bending much around the curvature of the earth and being blocked by structures and hills. Hence their range is limited. Television broadcasting antennas are placed on tall towers standing on high ground, so that the radio signal which car-

ELECTRONIC CIRCUIT OF A TELEVISION TUBE



In the television kinescope, or picture tube, an electron beam faithfully reproduces the scanning action of a television camera to produce images on a light-sensitive screen.

ries the television program may travel as far as possible before the curvature of the earth causes it to go off into space.

A radio signal that carries a television program must vibrate within a fixed number of megacycles so that it may remain within its channel and avoid interfering with signals in the channels that are on either side of it.

In the United States, each channel has a range or bandwidth of six megacycles. For example, Channel 2 includes the frequencies between 54 and 60 megahertz. Within this precise range of radio frequencies must be encoded the picture information, the accessory signals of the picture, and the information about the sound accompanying the picture.

RECEIVING THE SIGNAL

A prominent feature of many towns is the forest of television antennas mounted on roofs or chimneys. These devices pick up broadcast signals and lead them to receivers. Indoor antennas are feasible only if the broadcast transmitter is near at hand. The signal is weakened as it speeds farther out in space, and outdoor antennas are then required to intercept it properly. The orientation of an antenna and its size have much to do with the clarity of the picture that is received on the screen of the receiver.

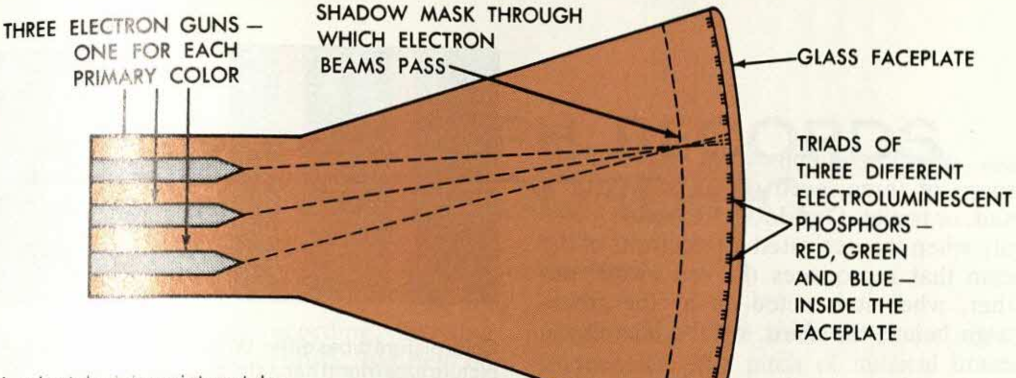
After the radio signal goes into a receiving antenna, it travels from it through a lead-in line of two parallel wires or through a coaxial cable and then enters the television receiver. Here it is amplified and is used to guide the vibrations of an electrical oscillator. The signal which traversed space in the form of electromagnetic energy is now again in the form of electrical energy. This electrical version of the radio signal is separated into a video signal which guides the action of the kinescope, or *picture tube,* and an audio signal which guides the action of the speaker.

A diagram of the picture tube is shown. In this device an electron gun directs a beam of electrons to an electroluminescent coating on the inside face of the tube—a coating that emits light in response to an electrical field. Electroluminescent particles are known as *phosphors*. Hence the electroluminescent coating on the inside face is sometimes called the *phosphor coating*.

Around the neck of the television tube is a yoke of deflection coils, carrying currents that bring about magnetic fields. It is these fields that guide the electron beam as it passes from the electron gun to the screen of the tube. The blanking and synchronizing information that formed part of the original video signal causes the movements of the kinescope beam to follow faithfully the scanning action in the television camera tube.

Each point on the electroluminescent coating in the kinescope will glow just enough to reproduce the brightness of the same point in the image that is being scanned by the electron beam in the camera tube. Meanwhile the audio signal has caused sound to be produced through the loudspeaker.

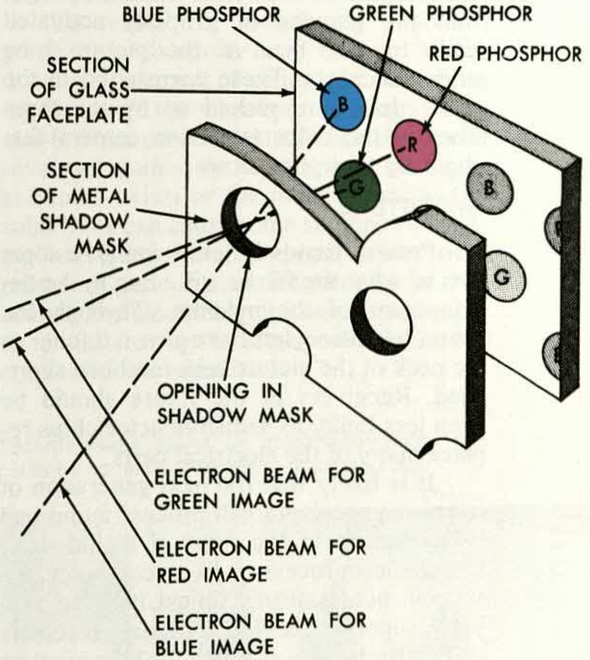
In receivers manufactured in the United States, when the video signal is weakest, the screen of the picture tube appears to be brightest. If no picture information at all is being received, the face of the tube is com-


THREE ELECTRON GUNS — ONE FOR EACH PRIMARY COLOR
SHADOW MASK THROUGH WHICH ELECTRON BEAMS PASS
GLASS FACEPLATE
TRIADS OF THREE DIFFERENT ELECTROLUMINESCENT PHOSPHORS — RED, GREEN AND BLUE — INSIDE THE FACEPLATE

A color-television picture tube.

pletely bright. This is called *negative picture transmission*. The picture is said to be in *negative picture phase*. *Positive picture transmission* is used in some other countries. In positive transmission the face of the picture tube receiving tube appears to be darkest when the picture information in the video signal is weakest. The viewing face of the tube is completely dark when no picture information is being received.

Sometimes a dim copy that is slightly to one side of the main image will appear on the face of the picture tube. The dim copy is called a *ghost*, or *ghost image*. It results when some parts of a radio signal take longer to get to the receiver than other parts because, instead of proceeding in a straight line, they have been deflected by intervening obstacles, such as buildings. Now and then, random radio signals in the receiver will produce *snow*—that is, white spots in a black and white picture. In color pictures, random spots of different colors are known as *confetti*. The spots are often due to passing automobiles. The sparking action of the spark plugs in the motors of these cars creates weak electromagnetic waves, which affect television receivers.


BLUE PHOSPHOR
GREEN PHOSPHOR
RED PHOSPHOR
SECTION OF GLASS FACEPLATE
SECTION OF METAL SHADOW MASK
B
R
G
B
G
OPENING IN SHADOW MASK
ELECTRON BEAM FOR GREEN IMAGE
ELECTRON BEAM FOR RED IMAGE
ELECTRON BEAM FOR BLUE IMAGE

Details of a shadow mask and color triads (groups of three phosphors) in a typical color television picture tube.

COLOR TELEVISION

Color television has made imposing progress since the 1950s. It is based on three primary colors—red, green, and blue—which can be mixed together so as to produce any visible color.

There are three tubes in the color television camera. Light from the scene that is being televised passes through a lens and then through three mirrors, known as *dichroic mirrors*, which serve as filters. Each permits the light of one of three primary colors—red, green or blue—to pass into one of the three camera tubes, while it reflects the other colors. Each camera tube then scans the image of one of the primary colors. The three picture signals that result are transmitted over the air and reach the color television receiver. The picture tube of this receiver contains three electron guns. Each of the three picture signals that had been sent out over the air controls the action of one of the electron guns.

On the inside of the receiver faceplate have been deposited many thousands of dots of electroluminescent material in groups of three, each group making up a *triad,* or triplet. One dot in each triad glows only when it is activated by electrons of the beam that reproduces the red image; another, when it is acted on by the green-image beam; the third, by the blue-image beam.

A *shadow mask*—a perforated metal plate—is set near the inside of the faceplate, as shown. The three electron beams pass through the holes in the shadow mask and strike the triads. The mixture of light from the glowing of properly activated triads on the face of the picture tube produces colors. These correspond to the colors that were picked up by the three tubes in the color television camera that originally took the picture.

THE FUTURE

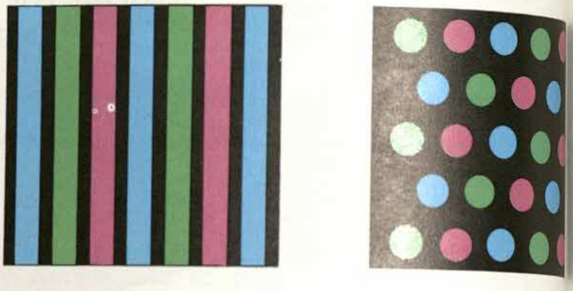
Present trends in television give some idea of what the future will bring in the development of the medium. Through the years, television sets have grown thinner as the neck of the picture tube has been shortened. Receivers of the future should be even less bulky as semiconductor chips replace many of the electrical parts.

It is likely that the next generation of television receivers will process audio and video signals in the form of digital data. Using microprocessors like a computer, the set will automatically adjust itself to provide superior fidelity. Digital receivers could also be programmed to show pictures from two channels simultaneously, store or freeze frames, and decode text transmissions that are broadcast along with the TV image.

As television cameras and video tape recorders become simpler, smaller, and less costly, more and more people are making their own television recordings, just as many people make magnetic sound recordings at home today.

Cable television (CATV) is a system of transmitting pictures through cables, instead of through space or air by means of microwaves. Receivers are assured of clear images that are not affected by all kinds of outside interference. CATV has been generally successful, and it may become the prime mode of television broadcasting sometime in the future.

Worldwide television coverage has been greatly aided by a number of artificial communication satellites orbiting the earth. Television has also succeeded in beaming dramatic scenes of space exploration.


Color picture tubes differ. While the conventional U.S. picture tube (right) has a shadow mask that produces points of color, some European sets have a structure that produces lines of color (left).

Television sets are mass-produced. This group of color sets is undergoing tests at a quality-control laboratory.

La Radiotechnique

PHONOGRAPH RECORDS AND RECORDING

by Robin Lanier

The phonograph recording, invented before the turn of the century, has held on to its popularity in our living rooms in spite of the enormous successes of radio, television, and lately, the videocassette recorder, all of which have brought new forms of entertainment into the home. In recent years, phonograph records have grown more popular than ever.

The reason for the lasting hold of phonograph records on our loyalty is mainly the very broad range of material they offer and the total selectivity of the system—that is, the buyer gets exactly what he or she wants, and can play it whenever it is wanted again. Music covers the whole range through classical, to jazz, pop, rock, and Broadway shows; and spoken material includes plays, language instruction, and many other specialized kinds of programs. Virtually any kind of sound that a number of people might want to hear over and over has been put on records. Historical events are an important source of material—speeches, political happenings, and accounts of disasters, such as the famous eyewitness report of the burning of the great airship *Hindenberg* at Lakehurst, New Jersey, in 1937.

HOW THE PHONOGRAPH RECORD WORKS

Sound is a train of pulses in air pressure that travel from the source to the listener's ears. We can call them *vibrations* of the air. The ear responds to such vibrations over a range of rates, or *frequencies,* but not to vibrations outside that range. If the vibration is no slower than about 20 times per second (20 Hertz, or Hz) and no faster than about 20,000 Hz, the ear sends a sensation of sound to the brain.

The pitch of the sound depends on the frequency. From 20 Hz up to about 200 Hz is the bass range. Middle C is at 256 Hz. From that point up to about 1,500 Hz is the middle range. The treble is at the higher frequencies. The pitch of musical instruments ends at about 4,000 Hz. Above that are the *overtones,* the very high notes that give the particular quality to music sounds, distinguishing a note on the violin, for example, from the same note on the piano.

To record the sounds for a phonograph, the vibrations must be used to lay down a solid track of some kind on a moving disc, with the vibrations causing a back-and-forth or other motion. When the disc is revolved again at the same speed, the back-and-forth twists or the indentations in the solid track can cause some sliding or "reading" device to vibrate or produce electrical pulses at the original frequencies of the sound. The electrical impulses are strengthened and sent to the loudspeaker to be reconverted into sound.

Records made sound an object—something that could be carried from place to place and sold.

J.P. Leloir

THE FIRST PHONOGRAPHS

Thomas A. Edison built the first phonograph in 1877. It was a cylinder covered with tinfoil and turned by a hand crank. Held just above the surface of the tinfoil was a diaphragm, a very thin, flexible disc, with a needle fastened to its center. When sound was directed to the diaphragm, it would vibrate in step with the sound. If the cylinder was turned at the same time, the needle, moving up and down, would cut a track in the tinfoil with hills and valleys. When the cylinder was rewound and turned, with the needle sliding along the track, the hills and valleys would push the needle, and thus the diaphragm, up and down. The diaphragm pushed the air off into a series of vibrations that were a close copy of the original sound.

The tinfoil phonograph, as the first instrument that ever preserved sound for replay, was praised highly in newspapers and magazines, but it could not become a product that people could buy for themselves. The tinfoil recordings could not be duplicated, and soon wore out. Turning the cylinder by hand gave an unsteady speed, and the pitch of the music wavered up and down as a result.

Edison later developed a system for recording on wax cylinders, which could be duplicated, and the "Edison cylinders" were quite successful for a number of years. The speed problem was solved by turning the cylinder with some form of motor.

But the advance in the phonograph that made it the basis of a great industry was the flat disc recording, the idea of Emile Berliner of Washington, D.C. We are using the Berliner system still today, with many improvements. By cutting the sound track as a spiral in the flat disc, Berliner made a recording that could be duplicated in great quantities at low cost. The first Berliner discs were pressed in hard rubber in 1896.

Another important figure in making the early phonograph a success was a businessman-engineer named Eldridge R. Johnson. He took the Berliner disc system, mounted the machines in attractive boxes, and developed a spring motor that turned the disc at a steady speed. His company, the Victor Talking Machine Company (later RCA-Victor), sold machines and records by the many thousands starting around 1910. He had the foresight to give his system glamour by inviting the most famous singers of the day, such as Enrico Caruso and other opera stars, to make the recordings.

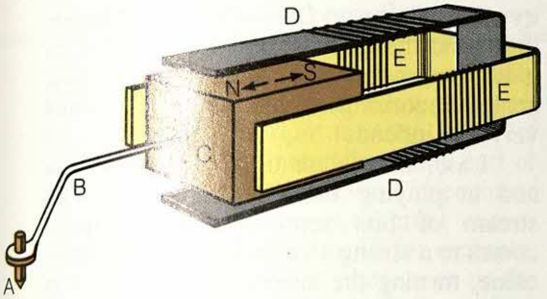
THE COMING OF ELECTRICITY

The early phonographs were all acoustically powered, that is, the power that cut the sound tracks came from the sound itself, and the playback system went directly from the needle and diaphragm assembly into sound. Musicians had to cluster around large horns that collected as much sound as possible for the recording machines. Although acoustic recordings were very successful on the market, they were quite tinny and muffled in sound quality. People liked them because even that approximate realization of the original sound was exciting.

Around 1925, the limitations of acoustic recording were swept away by the invention of the microphone and of electrical sound recording and reproduction. The microphone can respond to very weak sounds and turn them into electrical impulses that can then be amplified to any power level wanted. So the musicians could move away from the microphone into a normal arrangement, and all the instruments recorded in a balanced way.

The playback system also was soon electrified, with the sliding needle connected to an electrical generating device in the *pickup*. As the needle vibrates in response to the side-to-side motions of the track, the pickup generates corresponding electrical impulses, which again can be amplified and controlled precisely.

Electrical recording opened the way to a steady stream of improvements in fidelity through the 1930's and 1940's. The faithfulness of the recorded sound kept improving. A most important improvement came with *microgroove recording* in 1948. Early recordings had a standardized revolving



Shure Brothers, Inc.

A magnetic stereo cartridge, used in a dynamic pickup system. The diagram shows how such a system works. *A*, the stylus, is connected by a shank, *B*, to a permanent magnet, *C*. *C* can move freely between wire coils *DD* and *EE*, wrapped around U-shaped interlocking cores. As *A* passes over the record groove, its motion is affected by the patterns on the two groove walls. Variations in stylus motion are transmitted to permanent magnet *C*. As the latter moves, current is generated in coils *DD* and *EE*. The current passing through *DD* corresponds to the pattern of one wall of the record groove; the current passing through *EE* corresponds to the pattern of the other groove wall. The electric output of the currents is amplified and it passes to loudspeakers.

speed of 78 revolutions per minute. This meant that about four or five minutes of music was all that could be put on one side of a disc. This was the reason for the popularity of the record changer, which played a stack of records automatically.

Inventor Peter Goldmark at Columbia Records changed all that with microgroove records, which had a much finer groove on the record, for high fidelity, and more grooves per centimeter, and which also turned at the slower speed of 33⅓ rpm. The combined result was a capacity for up to a half hour of music on each side of the disc. Getting so much music on one record stirred the record buyer greatly, and the record industry enlarged several times over in the next years.

Another big step was the advent of *stereophonic recording* on discs in 1957. In a stereo recording there are really two separate recordings of the same music, picked up from different positions, or at different angles, in the recording studio. Normal hearing gets two slightly different accounts of the same music because of the separation of the two ears on the head. A sound at the right, for example, arrives at the right ear a little sooner and a little stronger than it reaches the left ear.

These small differences are used by the hearing system to give us a sense of the direction the sounds are coming from, and also of the space around the sounds with its *reverberation,* or echoes. The reverberation adds measurably to the power and vibrance of the music.

By recording two separate versions of the sound and sending each to a different loudspeaker, stereo recording can supply much of the directionality and spaciousness of the original. It is not a perfect replica of the original, but it is far closer than one-channel, or *monophonic,* recording. Virtually all reproduced sound is in stereo today because it is, indeed, far more satisfying than "mono" sound.

In the early 1970's, there were several attempts to make a commercial system of four-channel, or *quadraphonic,* sound on discs. This can come even closer to the original spaciousness and directional qualities in the music. However, four-channel recording on discs did not succeed in the market, largely because of intense competition among different methods. One form of quadraphonic reproduction is flourishing —movie sound, in the system called Dolby Stereo used in many movies today, as announced on theater marquees.

A NEW DISC SYSTEM

In 1983 a totally new kind of phonograph disc just began to reach the market. It showed promise of taking over the supplying of recorded music in the home within the next several years, as people buy the new machines and records. It is called the Compact Disc, and it uses two technical systems: *digital recording* and *laser beams* for making the record and playing it.

All recording until the recent advent of digital recording has been *analog recording*. This name derives from the fact that the ups and downs of the electric current, the swings of the track on the record, are in a sense pictures, or analogs, of the vibrations of the sound waves. When a sound

SONY

One version of the Compact Disc player, with an accessory remote control device.

wave rises to a certain height, the track on the record swings to its height at the same rate, so the solid wave in the record track would have the same shape as the original sound wave.

Digital recording is completely different. The original analog electrical impulses from the microphone, representing the sound, are broken up into many thousands of tiny samples. Each sample automatically gets a number that tells how strong the electrical signal was when the sample was taken.

These numbers are in binary notation, using only 0 and 1 (or "on" and "off"), just as the numbers in digital computers. The numbers can be carried through the recording process as an extremely fast stream of 0's and 1's, or "bits." When we want to recover the original sound, the numbers tell us specifically and quite precisely how strong the original sound was at every instant, and we can reconstruct the sound with the proper equipment.

The advantages of digital recording come from that very fact, that a number is specific—it cannot be a little less or a little more than it should be. Analog recording has always had more or less "slippage," with the shape of the waves at the end not quite the same as those at the beginning, which adds distortion. But the stream of bits can retain a series of numbers exactly.

Digital recording is not completely without distortion, but the distortion is so incredibly small that we can say that it has been effectively eliminated. Thus, the fidelity of the Compact Disc is at a new, higher level, and the quality of the music heard on it is even more thrilling than on the best analog recordings—which are themselves very fine indeed.

Laser beams are used both in making and in playing the Compact Disc. The stream of bits representing the music comes to a strong laser in the recording machine, turning the laser on and off in step with the 0's and 1's. The bursts from the laser cut a series of extremely small indentations in a spiral shape in the spinning master disc. Thus, the succession of 0's and 1's is preserved in solid form, just as the wave shapes in analog recording are converted into solid form.

Through a series of processes, the master disc can be duplicated thousands of times to make the playing discs. Each playing disc—about 10 centimeters across—has the same microfine succession of indentations on its surface. The disc is revolved on a turntable with a laser beam focused on the spiral, and moved along by electronic controls.

As each indentation passes under the laser beam, an electrical impulse is fed into the circuitry; the bit stream has been reconstituted in electrical form. It is converted, with extremely low distortion, into analog signals of the original sound and sent to loudspeakers for final reproduction into sound.

Since no solid device is in contact with the Compact Disc, there is no friction, and wear is eliminated. With a minimum of care, the records should last indefinitely. There are a number of other wonderful things about the Compact Disc. There is a coating of transparent plastic over the indentations on the playing side, which protects them from damage. The laser beam comes to a sharp focus right at the indentations, beneath the plastic. Therefore, small amounts of dirt or grease on top of the plastic are not "read" by the laser and do not cause distortion, noise, and wear, as do even small amounts of dust on an analog recording.

The position of the laser beam over the record is subject to very fast, very precise, electronic control. The recording can carry not only the music but identifying numbers for each selection or section of the music. Push buttons on the player allow the user, by punching in the right number, to direct the laser beam automatically to any part of the record in a second or two. The engineer calls this *random access,* a great convenience in a playing system. If, for example, you want to play band number seven on the record first, and then numbers three, five, and six, in that order, you can key those numbers in and the machine will automatically play those selections as you ordered them.

The recording companies are beginning to produce recordings on the Compact Disc, and the rate of production will go up sharply over the next several years. However, the companies will also continue to produce recordings in analog form, often the same music, because the great majority of people will still be using analog playback equipment for some years. The changeover to the Compact Disc will take time. Luckily, the best analog equipment has reached a very high level of fidelity.

MAKING RECORDINGS: ANALOG AND DIGITAL

Whether the recording will be issued as an analog disc or as a digital Compact Disc, it starts today with the making of a master tape in a recording studio or concert hall. Master tapes are almost always digital because that reduces greatly the noise and distortion in the tape recording process itself.

For classical music, the orchestra is usually spread out in front of two or more microphones—at least one for each stereo channel—and the operator, in a separate control room, adjusts the settings until the instrumental sounds are balanced in the way that the conductor wants. An alternative method is to record each section of the orchestra on a separate track on the recording machine, which may have as many as 24 or 32 tracks side by side on the tape. The different sections are separated by putting a separate microphone for each up very close to that section.

Later, in a process called the *mixdown,* the operator can collect the many tracks into two for stereo, adjusting the level of each section of the orchestra as it is rerecorded on another tape. The first method, of balancing the music for the original take, is more difficult and requires careful microphone placement, but it is preferred by many recording engineers.

In popular music, the many-track method with later mixdown is often carried even further. The musicians may be separated a good distance from each other in the stereo, so there is no "leakage" from one to another in the separate tracks on the tape. In fact, the musicians do not all have to play their parts at the same time or in the same place. The individual parts can be recorded separately, if at least one is used for timing the others, and brought together for the mixdown later.

This system, very common in rock music, allows the selection to be, in a sense, created in the mixdown studio. The

Records are molded from stampers through a combination of pressure and heat.

Kitrosser—Revue de l'electricite

© Laimute E. Druskis/Taurus Photos

High school students in a radio club use standard 33⅓ rpm microgroove records as well as tape recordings for broadcasting music.

operator can give each instrument the weight desired, and can choose among the several "takes" for the one preferred.

COPYING THE RECORDS

Somewhat similar methods are used in making copies of analog and digital recordings. Analog starts with using the master tape to cut a master disc in a soft lacquer. The cutting head moves over the revolving master disc, and the signals from the master tape vibrate the cutting stylus, which cuts the fine track in the surface of the lacquer. Signals for one stereo track are cut at 45 degrees into one side wall of the groove, and signals for the other stereo track at right angles to the first, in the other sidewall. The stereo pickup in the player resolves the motions of the playback stylus in the two stereo tracks.

The lacquer disc receives an extremely fine coating of metal, and a series of metal replications produces, finally, the *stampers*. These are negatives of the recording; the groove is a tiny hill on the surface. Stampers are used to make the final copies in presses that act very much like waffle irons, with the plastic material flowed in under heat and pressure.

The digital master disc, as already described, has a spiral of small indentations produced by the recording laser. It, too, goes through a series of replications that end up with negative stampers used in making the copies. But the process has to be controlled with much higher precision than does the analog process. The indentations are a micrometer or so across—a millionth of a meter. There are many millions of them on one record side, and their spacing must be exactly right. Compact Discs have to be copied, therefore, in special equipment under near-laboratory conditions. The extra care is worth it. The new discs will bring us even greater musical pleasure than we have had from records in the past.

TAPE RECORDERS, CASSETTES, AND CARTRIDGES

by Thomas E. Hitchings

Tape recorders have made home sound recording increasingly convenient and popular. People can now make a permanent record of their favorite music or their own thoughts at the push of a button. As a sound-reproducing medium, tapes have a few advantages over phonograph records. They show almost no wear after repeated playings. In cassette form, especially, they are extremely compact. And when you tire of what is on the tape, you can simply erase it and replace it with something else.

THEORY

If you set a piece of paper over a strong magnet and sprinkle it with iron filings, the filings will arrange themselves on the paper along the magnetic lines of force. Tape recording depends on the fact that particles of magnetic metal are aligned by a magnetic field. Recording tape consists of a thin plastic backing, rather like camera film, coated on one side with particles of a magnetic oxide. The oxide side of the tape is passed over a small electromagnet, called the *recording head*, which causes the particles to line up as they move by. The pattern of the oxide particles on the tape's surface reflects the strength of the magnetic field as the tape passes over the recording head. That magnetic field, in turn, is controlled by the impulses from the microphone. Thus the alignment of the iron particles on the tape reflects the continuous pattern of sound waves striking the microphone.

In playback, the tape is simply wound back and passed over another electromagnet in the same direction. As the waves of aligned particles pass over this *playback head*, they cause a small current to flow in the magnet. These faint signals are amplified and played back through loudspeakers.

The idea of magnetic recording was first worked out in 1898 by a Danish engineer, Valdemar Poulsen. His design was based on coated wire rather than tape. Primitive recorders using wire or paper tape were developed in the 1930s. In the 1940s modern magnetic tape was developed by German scientists. It was quickly adopted by recording companies for making their master recordings.

The first tape machines were quite bulky, but home machines no larger than a small suitcase were soon introduced. Miniature tape formats—cassettes and cartridges—appeared in the 1960's.

OPEN-REEL TAPE RECORDERS

All tape recorders are similar in their basic principles. They differ chiefly in such

Recording a master tape on a reel-to-reel recorder. After the tape is edited, it is copied in cassette form. Cassettes synchronized with slides are widely used in educational and promotional programs.

3M Company Photo

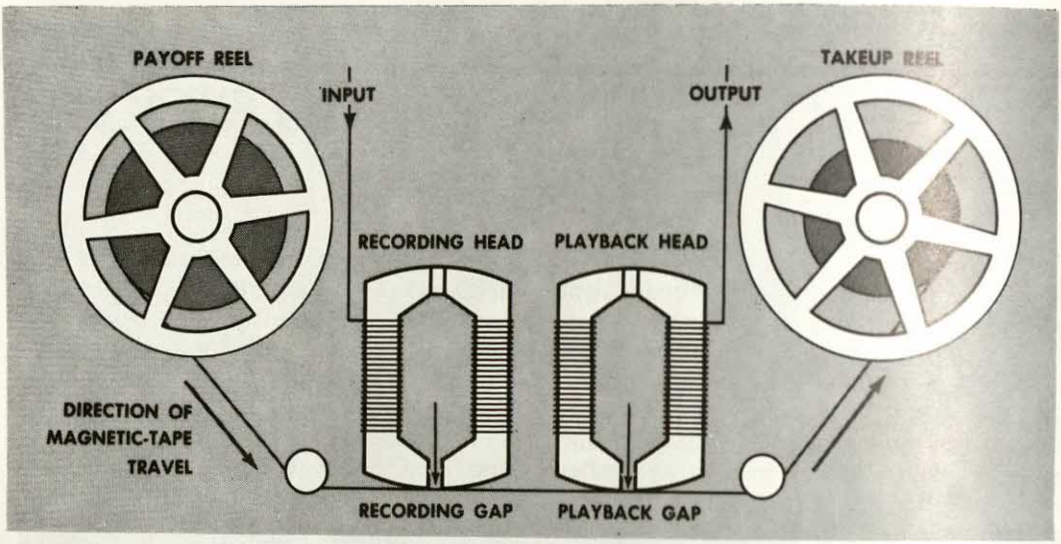


Diagram showing how a tape recorder works. The vibrations of sound waves are changed into electric impulses of varying strength by a microphone. These impulses (indicated above by "input") affect the strength of the magnetic field of the recording head, which is a magnet. As the tape moves from the payoff reel past a gap in the recording head, its metallic coating is magnetized, the pattern varying according to changes in the magnetic field of the recording head. The tape then moves to the takeup reel. For playback, the tape is moved past a gap in the playback head. A small electric current of varying strength is produced. The current (indicated by "output") passes through an electronic amplifying system and to a loudspeaker; here it is changed into sound waves.

matters as tape packaging, tape size, and recording speed. The basic features can be seen most clearly in the *open-reel* tape recorder.

The tape in an open-reel machine, as the name implies, is wound on an open spool. The recorder has two tape spindles. A full reel, the *payoff reel,* is placed on the left spindle, and an empty reel, the *takeup reel,* goes on the right. The tape is threaded past the heads and onto the takeup reel by hand. The speed of the tape's turning is controlled by a roller to the right of the heads. A slight spin is also given to the two spindles, just enough to keep the tape tight as it moves past the heads.

In recording, the first device in the tape's path is the *erase head.* It applies a strong magnetic field to the tape before it reaches the recording head, removing any signal already present on the tape. If there were no erase head, a new recorded signal would simply be added on top of any old ones. During playback, the erase head is switched off.

The tape next passes the recording and playback heads. In many machines a single head serves both purposes, but the best machines have separate heads. The advantage of this system is that it permits you to *monitor* the tape—play it back—as it is being recorded. The playback head is located to the right of the record head, and it plays the signal a split second after it has been recorded. Flaws in the tape and improper volume settings can be identified immediately.

The tape recorder divides the surface of the tape into parallel bands, or *tracks.* Most home open-reel recorders put four tracks on a tape, two stereo channels on each side. Quadraphonic recorders make use of all four channels at once and record on only one side of the tape.

Standard tape is either 0.025 or 0.04 millimeters thick and a quarter of an inch (six millimeters) wide. Thinner tapes permit more tape to be wound on a reel, but they are also extremely fragile. The most commonly used tape recording speeds are $7^1/_2$ and $3^3/_4$ inches (19 and 9.5 centimeters) per second.

Professional tape recorders use tape up to two inches (five centimeters) wide and record at speeds of 15 or 30 inches (38 or 75 centimeters) per second. They can record anywhere from 16 to 40 parallel tracks on a single tape. The reason for the higher recording speeds in professional recording is that the quality of the sound is a function of tape speed. The higher the speed, the better the recording.

CASSETTES AND CARTRIDGES

Home tape recording was made immensely more convenient in the 1960s with the introduction of cassettes and cartridges. Both consist of extremely compact, self-contained units of tape. Both are played simply by snapping them into a machine and pressing a button.

Cassettes are really just open-reel tapes in miniature. The cassette enclosure contains miniature payoff and takeup reels, but only the portion of tape that comes into contact with the heads is exposed. Like standard open-reel machines, the cassette recorder divides the tape into four parallel tracks. When one side is full, the cassette is flipped over to record two more channels on side two. Cassette tape is little more than a half the width of standard open-reel tape, and the recording speed is only $1^7/_8$ inches (50 millimeters) per second.

Various advances have made up for the slow recording speed of cassettes. New tapes using chromium dioxide perform better than standard tapes at high frequencies. A technique, known as Dolby signal processing, helps to minimize background hiss. Improved drive mechanisms largely eliminate speed wobble, or "flutter." The very best cassette machines can make recordings that rival those of open-reel recorders.

One major advantage of the cassette is its size. A single cassette, small enough to fit in a shirt pocket, can hold up to 90 minutes of music. Another advantage is the convenience of not having to thread the tape. However, because the tape is sealed away, it is very difficult to edit or repair broken tapes. Finally, because of the slow recording speed, cassettes always lag behind open-reel recording in terms of sound quality.

Eight-track cartridges use standard quarter-inch recording tape. Unlike cassettes, the tape is joined inside the cartridge into a continuous loop, which passes the heads repeatedly. Thus there can be no editing of the tape at all. The tape is divided into eight parallel tracks, which embody four separate stereo "programs." Playing or recording starts at the beginning of Program 1. When the loop of tape reaches the starting point again, the mechanism switches over automatically to a second pair of tracks, Program 2. Each time the starting point is passed, the machine switches to a new program. When it reaches the end of Program 4, it turns off. Quadraphonic recorders use two programs of four tracks each.

Eight-track cartridges have benefited from many of the same advances as cassettes. Their relatively high flutter, however, makes them most suitable for less demanding uses, such as automobile tape players and portable machines.

Cassette recorders are popular on the education scene. These portable machines with their pop-in, pop-out tapes make the recording of classes and lectures an easy matter.

3M Company Photo

VIDEO CASSETTES AND VIDEODISCS

By Robin Lanier

Video cassettes and videodiscs have revolutionized home entertainment since the mid-1970's. Both provide sight-and-sound programs for use in the home. In both systems the user's standard television receiver is the display system. The program appears on the television screen.

In the video-cassette recorder system, the program is no magnetic tape in a cassette about the size of a small book. The cassette is slipped into the recorder, which is connected to a television set. In the videodisc system, the program is recorded on a disc much like a phono disc in size and shape. The disc is spun on a turntable that is part of a videodisc player connected to a television set.

The first successful consumer video-cassette recorder, or VCR, was the Sony Betamax. It came on the U.S. market in late 1975. By early 1981 some 20 firms were marketing about 60 models of VCR's. Worldwide sales reached nearly $1,000,000,000 in 1980.

Videodiscs were latecomers to the consumer market. The year 1981 saw the beginning of a massive market battle among three groups of giant electronic companies. Each determined to make its videodisc model dominant throughout the world. The videodisc industry thus has to face "in-the-family" competition. It must also battle the already well-established video cassettes for the consumer pocketbook. Failure of videodiscs to gain a permanent footing in the consumer market would be a large loss. That is because videodiscs have abilities for entertainment, information storage, and instruction that go far beyond anything ever developed for home use.

VIDEO CASSETTES

The VCR brings the user two things never before available in the home. One is the extremely easy-to-use magnetic tape system for playing pre-recorded video programs. The other is the ability to record video programs. You can record any program you want from television. You can then view the program at any time.

In addition the user can invest in a video camera and can record any "live" scene. The VCR-camera-TV set system becomes a home movie system. It has the virtue that the "movies" can be seen just a few moments after they are shot. This ability to make home recordings is one great advantage the video cassette has over the videodisc. All videodiscs must be commercially recorded.

Since the late 1970's thousands of programs have been recorded on cassettes. The majority of them are movies from the large film studios.

For home recording of television programs, all popular VCR models include automatic timers. The timer turns on both the television set and the VCR at any preset time to "catch" a program on the air when you are away from home. You can then see the program whenever you want.

CASSETTES

All VCR's use the same form of cassette: a flattish box about 6 inches by 4 inches by ¾ inch. It has two reels, one at each end. Magnetic tape, ½ inch wide, is wound around the reels. When the cassette is pushed into the recorder and the "start" button depressed, the machine automatically picks up a loop of the tape. It then moves the tape over magnetic heads inside the player, the tape going from one reel to the other.

Although all cassettes have the same form, there are two different "formats," or arrangements of the signal, on the tape. One is the "Beta," originated by Sony in the Betamax. The other is the "VHS," originated by Matsushita (Panasonic). The two

Two dancers discuss their own performances on a video cassette recording made for later review.

Zenith Radio Corp.

systems differ in a number of ways, but there is no overall quality difference. Recordings made on a Beta machine cannot, however, be played on a VHS machine, and vice versa.

RECORDING ON TAPE

Tape recording basically involves putting a pattern on magnetic tape. The pattern corresponds to the electric signals of the program being recorded. Signals from the program affect the magnetic field of a recording head. The tape passes over this magnetic head and is magnetized. It is magnetized in a pattern corresponding to the strength of the magnetic field—and thus to the program signals. In playback, the magnetic pattern on the tape is changed back into signals that are converted into a sight-and-sound program.

Both VHS and Beta use a "helical scan" system. The tape moves horizontally at a slight angle in a helix. It winds around a drum that is about three inches in diameter. The magnetic heads that record the program are fixed on the circumference of the drum. The tape moves slowly, about one-half to one inch per second. This slow speed is necessary so that the quantity of tape in one cassette will last from one up to five, and even six, hours. The drum also moves. It rotates at a speed much faster than the tape. The circumference of the drum therefore moves the magnetic heads repeatedly across the section of tape that is around the drum.

The combination of these two motions puts a series of magnetic tracks on the tape. These tracks are very thin, parallel, and very close together. They make a slight angle with the axis of the tape. The result is a recorded track that is many times as long as the tape itself. Each of the slightly slanting "lines" on the tape is played separately, one after the other. Only in this way could the immense amount of information in a video program be packed onto magnetic tape moving so slowly.

PLAYBACK

During playback the tape must go around the drum in the same position relative to the heads that it had when the recording was made. The positioning must be very accurate—within an extremely small dimension of one micron, or 1/25,000 inch. The drum itself must have no irregularity—again down to the same tolerance of about one micron. The magnetic head, in other words, must line up with one of the slanting tracks on the tape—and just the right one.

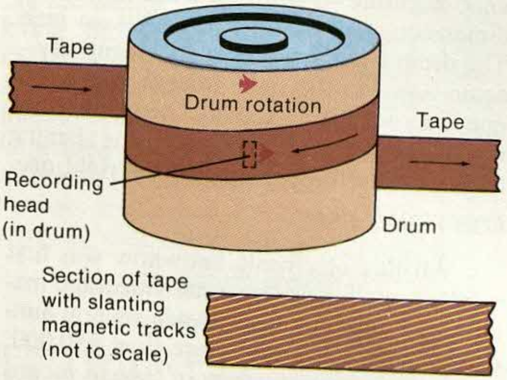
FOR HOME USE

All this electronic knowhow was first worked out for professional videotape machines. These machines weigh several hundred pounds, and cost more than $50,000. They use a large quantity of tape to record a half-hour program. The basic problem then was how to get the enormous amount of information in a video program onto a small quantity of tape. The tape had to fit in a home machine of small size and low cost.

The amount of information is measured in *bits* (short for binary digit). A bit is the basic technical building block of all information. Any program can be broken down into the number of bits making it up. With any given recording technique a given area of tape will hold a certain maximum number of bits. This is the storage density of the tape and the technique. Other things being equal, the amount of information goes up directly with the area of tape being used.

Professional machines using one-inch tape use about 120 square feet of tape to record a one-half hour program. Betamax and other similar home VCR's put a one-half hour program on about five square feet of tape. Because of this difference, home video tapes cannot match the quality of professional video tapes. Nor do they pretend to do so. The quantity of tape practical in a home design simply doesn't have the storage density to hold all the information in a fully detailed program. Home VCR makers have, however, succeeded in producing a picture that is fully acceptable for home playback.

In video-cassette recording, a program is put on a tape by passing it over a magnetic recording head. This magnetizes the tape in a pattern corresponding to the program signals.


Tape
Drum rotation
Tape
Recording head (in drum)
Drum
Section of tape with slanting magnetic tracks (not to scale)

It may be interesting to note here that the videodisc has inherently many times the storage density of magnetic tape. It is potentially able to provide better reproduction than even present professional tape systems. But before we discuss videodiscs in detail, let's take a look at some of the special features many VCR's contain.

SPECIAL FEATURES

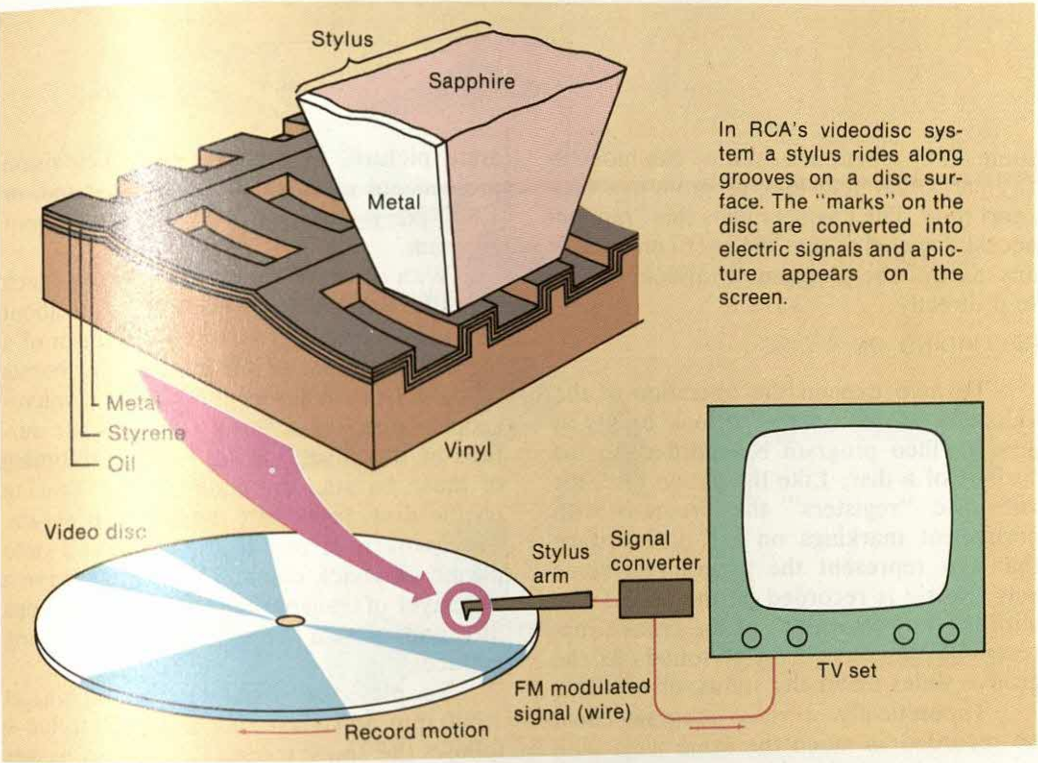
Home VCR makers, with picture quality the consumer quickly liked, have gone on to give the consumer a raft of operation features. Long playing time was one of the first features. The original Betamax ran for one hour on one cassette. Rival machines started a race that has ended with machines that run up to five and even six hours on one cassette. There is a price for long playing time, however. The extra playing time is achieved either by using thinner tape or by running the tape more slowly. Both are likely to degrade quality.

Automatic timers have become very elaborate. Some can be programmed for a number of days in advance to turn the recorder on a number of different times. Many models are also available with built-in television tuners. You can then record an off-air program without tying up the regular television set.

Most machines now also allow the user to "freeze" a frame—that is, to hold any picture still on the screen. Fast forward and reverse speeds can also be had as can remote controls, and automatic rewind at the end of the tape. You can get slow motion and "instant replay" on the VHS machines. You cannot get this feature on Beta-type machines.

VIDEODISC

The videodisc has been in the making since the early 1970's. The first kind to be sold was the "all-optical" system developed by the Dutch electronics company Philips. It was made by Philips' U.S. subsidiary, Magnavox. It came on the U.S. market in 1980 with the brand name "Magnavision." Later in 1980, Pioneer, a Japanese company, brought out a variety called "LaserDisc." LaserDisc uses essentially



In RCA's videodisc system a stylus rides along grooves on a disc surface. The "marks" on the disc are converted into electric signals and a picture appears on the screen.

the Philips system. Recordings made for Magnavision are playable on LaserDisc, and vice versa.

Two other, entirely different, videodisc systems appeared on the U.S. market in 1981. One was the "SelectaVision" system developed in the United States by the RCA Corporation of America; the other was the "VHD" system, invented by the Japanese firm JVC. Recordings were not interchangeable between SelectaVision and VHD, nor between either of these two and the Philips system. This means that each of the three groups must make or encourage the making of recordings for its system. Obviously buyers will respond to the videodisc only if there are a large number of attractive programs available.

Videodiscs must face this "in-the-family" competition plus a late start against video cassettes in the consumer market. The videodisc has, however, certain advantages that may secure it a firm place in the consumer market. With its high storage density, the videodisc can do amazing things. It can store staggering quantities of information of any kind on a single disc. Any item is retrievable almost on instant call. It has seemed a good presumption that consumers would buy centrally recorded videodiscs on a large scale, just as they now buy centrally recorded phono discs.

CHEAPER—AND WITH RANDOM ACCESS

The expectation for a large consumer market also springs from the inherently lower cost of the disc, as compared with the same programming on the video cassette. A magnetic recording must be played through to be duplicated. The videodisc, like the phono disc, is stamped out a whole disc at a time. Moreover, the plastic material of which the disc is made costs much less than the magnetic tape for a program of the same length.

The disc has another important advantage. The whole program, a half-hour to an hour long, is right there on the surface of a single disc. On the cassette, as on any magnetic-tape recording, the program is spread through up to 2,000 feet of tape, and to reach any part of it the user must play through the tape to the desired part. Even with the tape shuttling through the machine at high speed, this is awkward and time consuming.

The videodisc player, with the aid of

some fancy electronic circuits, can move to any part of an hour-long program in a very short time. The engineer calls this "random access," meaning that the user can specify any part of the program at random and go to it directly.

RECORDING ON A DISC

To help explain the operation of the videodisc system, we shall look briefly at how a video program is recorded on the surface of a disc. Like the phono disc, the videodisc "registers" the program with permanent markings on the disc surface that can represent the program in some way. Music is recorded on the phono disc with the tiny "wiggles" of the groove representing the succession of sounds as the groove slides under the stylus, or needle.

Theoretically, a video program could be recorded in much the same way, with microscopic wiggles in a groove on the surface. But a sound program has frequencies up to about 20,000 per second. A video program has frequencies up to 6,000,000 a second (and beyond in some systems). These extremely high frequencies cannot be handled by a mechanically-vibrating system like the familiar phono stylus. It is best done with some weightless signal, like a light beam or a change in electrical charge.

Moreover, the amount of information in a video program is several hundred times the amount in a sound-only program of the same length. A large number of separate "marks" on the disc are needed to represent a large number of information bits. Thus to record a video program in the 60 square inches or so available on the disc surface, the marks have to be extremely small.

OPTICAL SYSTEM

There are several ways of putting the "marks" on the disc. In the Philips optical system, a beam of light from a laser is used to put the marks on the disc, and to "read" them from the spinning disc in playback. The disc turns at 1,800 revolutions per minute (rpm) which means that each single turn holds one complete "frame", or separate picture, in the program. Television projects its pictures at 30 per second, or 1,800 per minute, or 54,000 in a half-hour program.

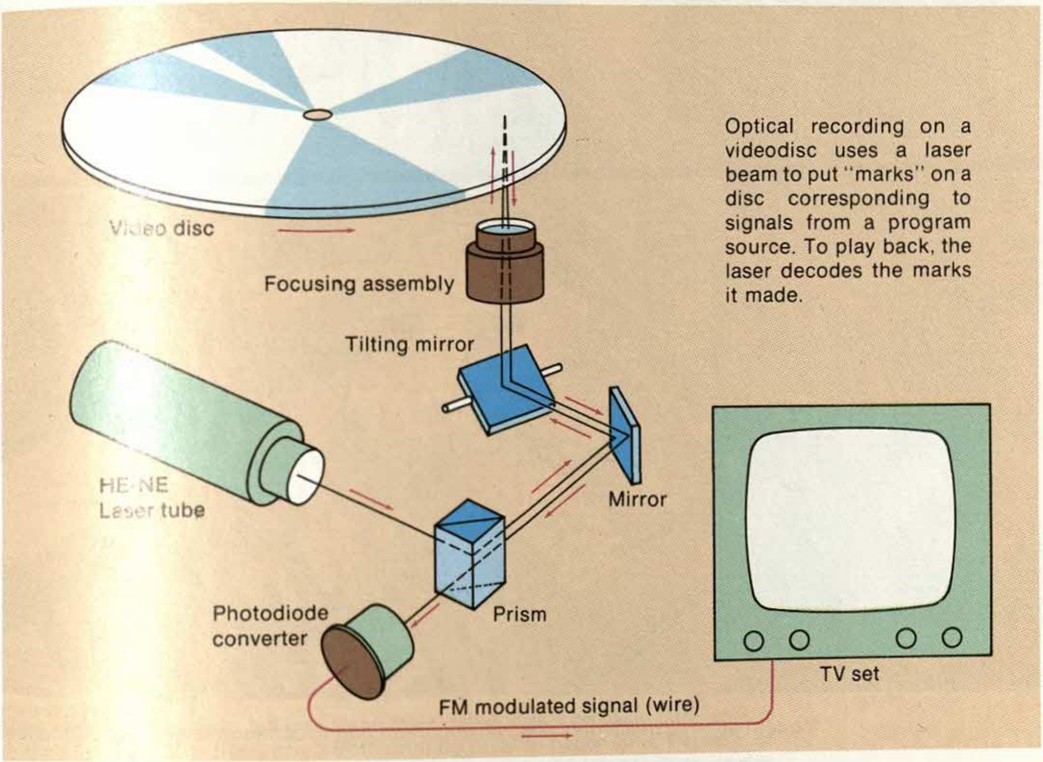
With one complete picture in each turn, the individual marks have to be about one micrometer across (one millionth of a meter, or $1/25,000$ of an inch). Tiny bursts of light from a laser gun produce microscopic "pits" in a spiral track on the surface of the disc. Variations in the timing of these bursts, and thus in their spacing on the disc, represent the video program. This pattern of pits is then stamped onto plastic playback discs. These discs have a thin layer of transparent material that keeps dirt and grease away from the playing surface.

To play the disc, it spins, again, at 1,800 rpm, and a laser beam – not a stylus – follows the spiral track. As each pit passes under, it reflects the light beam back into the machine. These returning flashes are converted into electrical impulses with the same time variations that the original program had, and the television receiver in turn converts them into the sight and sound of the program.

To keep the beam right on the one-micrometer width of the track, electronic circuits were developed that sense the position of the beam and automatically keep it on the track. This electronic control of the laser beam also allows the user to "freeze frame;" to move forward or back at normal, fast, or slow speed; and to repeat any section of a program over and over.

In an extension of the search capability, each frame can be given a number (visible in the upper left corner). With a small push-button device, the user can flash the playback right to the number he or she wants and have it held on the screen. This is random access at its fullest.

Consider what capabilities this opens up. With a little higher resolution than we have in standard television, each of the frames in a one-half hour program could be a page of readable type. As a final addition to entertainment capabilities, the optical videodisc has stereo sound of excellent fidelity.



Optical recording on a videodisc uses a laser beam to put "marks" on a disc corresponding to signals from a program source. To play back, the laser decodes the marks it made.

VHD SYSTEM—LASER PLUS STYLUS

The second system, the "VHD", is made with a laser in somewhat the same fashion as the optical system. However, the disc spins at 900 rpm, so each turn holds two complete frames, and the "marks" have to be about half as big as those on the Philips disc.

Playback is entirely different. A diamond stylus with a broad tip slides over the record surface. One side of the stylus has a very thin strip of metal. The lower, razor-like edge of this strip is just above the disc surface. The stylus is kept over the right track with electronic sensing circuits that function somewhat like those in the Philips system.

As each "pit" passes under the razor-like metal, it causes an abrupt change in the ability of an electric circuit to hold a charge—the "capacitance" of the circuit. These changes, converted into electrical impulses, go to the television set which converts them into the sight and sound of the program.

The VHD videodisc has rapid search through the program, variable speed forward or back, numbered-mode search, automatic repeat of any section, and stereo sound.

SELECTAVISION

In the third system, RCA's "Selecta-Vision," the disc turns at 450 rpm, so the "marks" have to be smaller again by half, or around 0.25 micrometer across. Not even a laser easily focuses this small, so RCA records with an electron-beam system, with the master disc in a vacuum chamber.

The playback system uses a stylus that rides a groove in the record, but picks up the program with a capacitance system much like that of the VHD disc. The player has fast search, forward and reverse, with the pickup lifted out of the groove. Sound in the early models is monophonic.

In both the VHD and the RCA, stylus wear will eventually make a replacement necessary; but life is apt to be very long in both cases.

The fate of the three systems on the market will be influenced greatly, of course, by the quality and quantity of the programming that each can offer. Meanwhile buyers of the videodisc or VCR systems will experience a vast enlargement of their home entertainment resources.

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Modern printing machinery plays an important part in communication and education.

PRINTING

by Richard Wendt

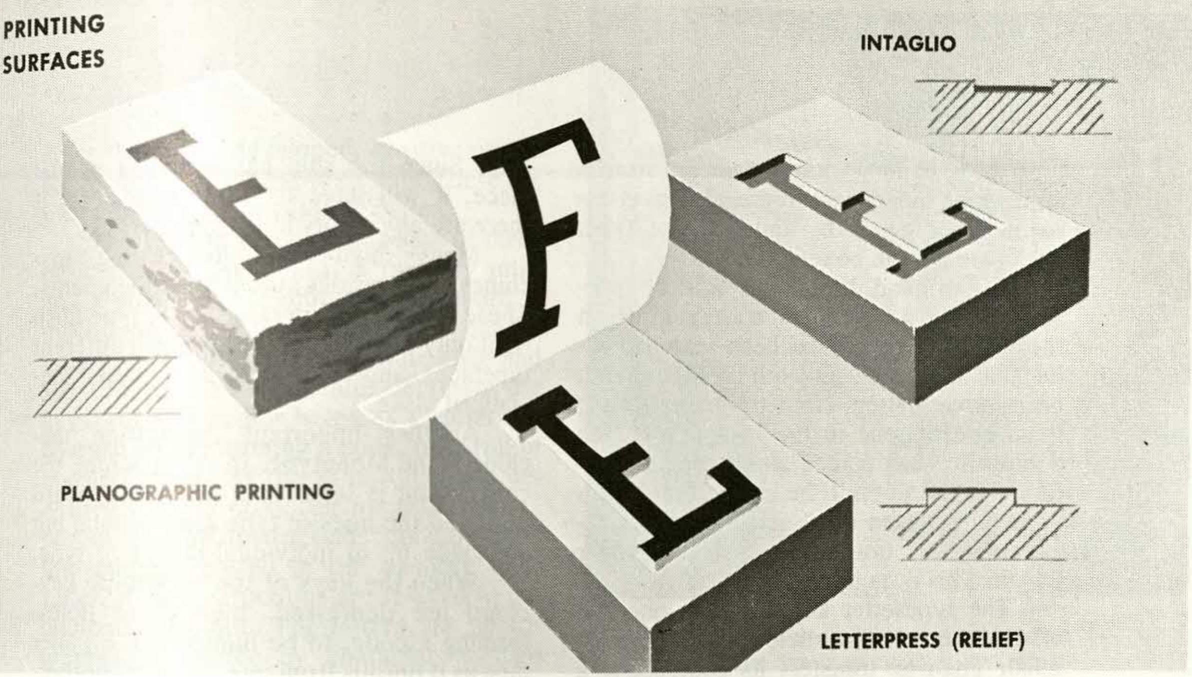
Printing, which turns out identical copies of text matter and pictorial matter in any desired quantity, is a key industry in our modern civilization. Presenting data and ideas in convenient form, it is an indispensable means of communication between people. Because of the great number of duplicates it provides, it assures the preservation of the record of human civilization. It plays an all-important part, too, in the spread of education, for its supplies educational materials at low cost.

The Chinese are credited with the invention of printing. They carved out wooden blocks to provide raised surfaces for words and pictures, and practiced *relief printing* (printing from raised surfaces) as early as the ninth century A.D.

Toward the middle of the fifteenth century, printing took a giant step forward. Johann Gutenberg, of Mainz, Germany, developed movable type and a method of casting duplicates from the original type. Gutenberg transferred ink from type to paper by means of a crude press. His chief undertaking was the printing, in the 1450's, of the famous *Gutenberg Bible*—the first complete book printed from movable type.

For over three centuries after Gutenberg's time, there was little change in the basic principles of the printer's art. Toward the end of the eighteenth century, there were many innovations. Among these was the development of lithographic printing.

A period of extraordinary growth in the development of the printing industry began with the application of photography to printing in the mid-nineteenth century. The last half of the century saw thousands of improvements, refinements, and variations in printing. There were two key developments in the 1880s. The perfection of the halftone screen led to vastly improved methods of reproducing illustrations, and typesetting machines freed the printer from much laborious hand-setting. Mass production of magazines, books, and newspapers became possible.



Most printing processes fall into three main categories. The basic difference is in the way the ink is transferred from printing plate to paper. In letterpress, or relief, printing, the ink is transferred from a raised surface. In planographic printing, or lithography, areas of the plate that are to be printed are coated with a substance that will not accept water. The intaglio printing process involves printing from indentations in the plate.

Today, the use of the computer in the printing process is opening a new era.

THREE MAJOR PROCESSES

There are many ways in which words and illustrations can be reproduced. Most of these processes belong to one or the other of three major groups: letterpress, planographic printing, and intaglio.

Letterpress is the oldest method of printing. In it, ink is transferred from a raised surface to the paper.

Planographic printing, or *lithography,* is based on the principle that water and grease do not mix. A plate is grained so that its surface is receptive to water. The areas of the plate that are to be printed are coated with a substance that will not accept water. The plate is dampened and greasy ink is applied to it. The ink is transferred only to the coated portions, which have remained dry. In modern practice, the inked portions of the plate are generally transferred to a rubber-covered cylinder and from this cylinder to the paper. This is called *photo-offset*, or *offset*.

Intaglio is the reverse of the letterpress printing method. In intaglio, the printing surface is below the surface of the plate. Ink is poured into small indentations, called *cells,* etched into the plate. Then the surface is wiped clean. The paper or other material is pressed against the plate, and the ink is drawn from the cells by capillary action. *Gravure* is an intaglio process.

LETTERPRESS PRINTING

Letterpress is applied to books, magazines, newspapers, catalogues, and many other kinds of printed matter. When it is done by skilled craftsmen, it is noted for sharp, brilliant reproduction.

TYPESETTING PROCESSES

The first step in letterpress printing (or in any other process) is to set the type. There are several ways of doing this.

Hand-set type. Until late in the nineteenth century, all type was set laboriously, letter by letter, and then carefully spaced out—all by hand. The type was made of wood (for the largest sizes) or metal. The type for a hand-set job is selected from a number of *fonts,* each representing an assortment of one size and style of type. Fonts are kept in boxes called *cases*.

In one hand, the *compositor,* or typesetter, holds a tray called a *stick,* in which the length of the line has been set by an adjustable sliding gauge. With his other hand, he removes letters from the case, setting them one by one in the stick. When the compositor has placed almost enough letters in a line to fill it, he inserts thin pieces of metal between words and sometimes between letters until the line is of proper length. This is called *justification*.

The typesetter keeps adding one line after another to the stick until it is almost filled. Then he transfers its contents to a long tray called a *galley,* which can hold a number of sticks. Rough proofs are taken from galleys on long strips of paper, called *galley proofs*. The proofs are corrected and appropriate changes are made in the type. It is now ready to be made up in page form or other required form.

Line-casting machines. Today much type is still set on the Linotype despite great inroads made by photographic typesetting systems. There are many Linotype models, but the operating principle is the same for all. It is based on the *circulating matrix*. A matrix is a metal mold from which typefaces are produced. The matrix travels from one part of the machine to another and then back again in the course of the typesetting operation.

The operator of the machine sits in front of a keyboard, which resembles that of a typewriter. As he presses the keys, each corresponding to a particular type character, the appropriate matrices slide down onto a moving delivery belt, which carries them to an assembly area in front of the operator. He inserts *spacebands* between words by tapping the spaceband key. A bell rings when the line is almost filled, and the operator *justifies* the line.

In the casting operation, molten metal is forced against the indented characters on the matrices. The metal cools, is trimmed, and then is ejected, sliding onto a galley. It is in the form of a solid line of type, called a *slug*. Since the slug has been set in one piece, it will have to be entirely reset if there are any errors in the line.

Many high-speed line-casting machines have various automatic attachments. These enable the operator to set type flush right only or flush left only, to mix different typefaces, and to perform many other specialized tasks.

Another important typesetting machine is the Monotype. In this machine the casting unit is separate from the keyboard unit, and the lines of type are not solid but are made up of individual pieces of type.

When the keys of the Monotype keyboard are depressed, they cause holes, forming a code, to be punched in a paper tape as it unrolls from one spool to another. As the punched paper tape is unrolled, it activates the casting mechanism. The matrix is brought into position so that the appropriate character will be over the mold chamber. Molten metal is then forced into the mold chamber and against the matrix set on top of it. An individual type character is produced having the shape of the mold chamber and with a raised letter or figure, corresponding to the matrix, on top. The type is cooled and then ejected onto a galley.

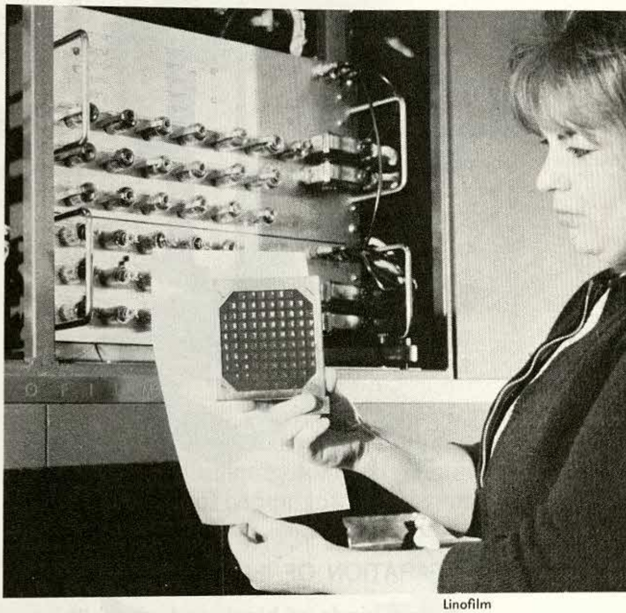
The Monotype is particularly useful in difficult typesetting, as in the case of textbooks with many intricate symbols. In Monotype work the printer can correct errors in a line by replacing individual pieces of type.

Photographic typesetting. All the machines we have mentioned hitherto are called *hot-metal* machines, because they cast type from molten metal. Several *cold-type,* or photographic, processes are used.

The Fotosetter was the first cold-type machine to be operated commercially. Like the hot-metal machines, it is based on the circulating-matrix principle. There are two important differences, however: the matrix has a transparent image of a character and the casting unit is replaced by a photographic unit that photographs the characters on the matrices as a line on a film. The lens of the camera can be adjusted to reduce or increase the size of the characters.

After the film is developed, positive proofs are made on either paper or film. These are then converted into printing plates.

The Photon machine consists of three basic parts: a keyboard, a memory unit, and a photographic unit. The keyboard is much like that of a typewriter, but can be preset to provide the appropriate style and size of type. As the operator depresses the keys, each character becomes a pattern of charged spots, forming a code, on a roll of magnetic tape. At the same time, a typewritten copy is produced for proofreading purposes. The instructions contained on the tape are stored in the memory unit. Later, these instructions are relayed to the photographic unit. The letters are photographed character by character at high speed according to the instructions from the memory device. The exposed film, which is on a continuous roll, is then developed and a paper or film negative or positive is obtained. Printing plates are made from the paper or film.



Linofilm

The Linofilm system for producing type characters on a photographic film uses this grid font, which contains the characters needed. The keyboard unit of the Linofilm is separate from the photographic unit. A third unit of the Linofilm can enlarge or reduce lines on a film, as required.

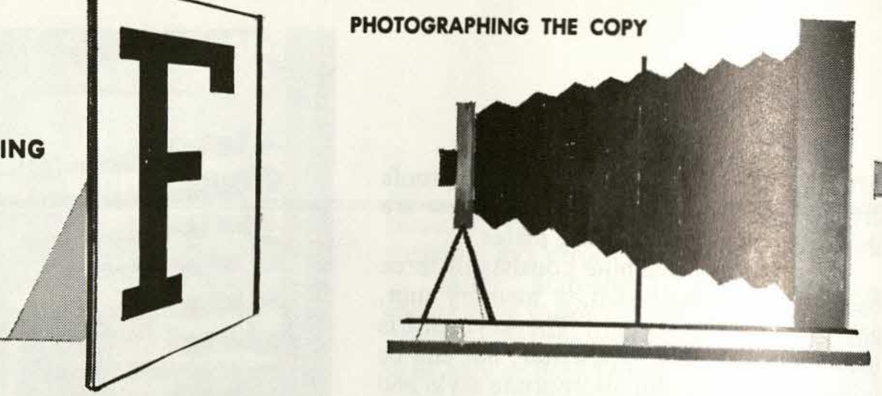
In the Linofilm system the keyboard unit produces tape and is separate from the photographic unit. Thus, the product of several keyboard units can be fed to one photographic unit. A third unit, a makeup composer, can enlarge or reduce lines on a film. The product of the makeup composer is a positive film ready for engraving.

The rapid spread of small business and home computers has been accompanied by great growth in the number of accessory printers in use. The output of some types

Advanced systems enable editors to deliver taped instructions directly to typesetting machines. The keyboard of this system combines the standard typewriter array with buttons that give complete typesetting instructions.

Harris Corporation

HOW A PHOTOENGRAVING IS MADE



If the letter *F* were not set in type but were instead drawn with pen and ink by an artist, a photoengraving would have to be made of the letter if it were to be used in a letterpress printing plate. The first step in making such an engraving is to photograph the original material. In the meantime, a metal plate has been coated with a light-sensitive solution. When the photographic negative is placed against the prepared plate and both are exposed to controlled light, the coating under the clearer portions of the negative—that is, the future printing areas of the engraving—is hardened.

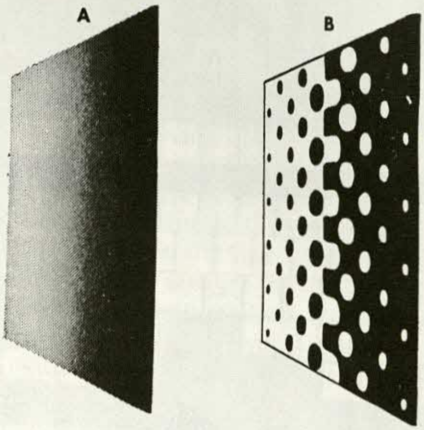
of printers approximates the quality of commercial photographic typesetting, and it may be photographed for conversion into printing plates.

PREPARATION OF ILLUSTRATIONS

Two kinds of black-and-white illustrations are used in letterpress work. *Halftones* are illustrations with varying tones —white, shades of gray, and black. The name *linework* is given to illustrations without varying tones.

Most pictures that are to be made into halftones consist of photographs or other continuous-type illustrations. To produce a plate suitable for printing, the photograph must be broken up into a series of small dots, varying in size and shape. When these dots appear on the printed page, the eye causes them to merge so as to create an illusion of different shades.

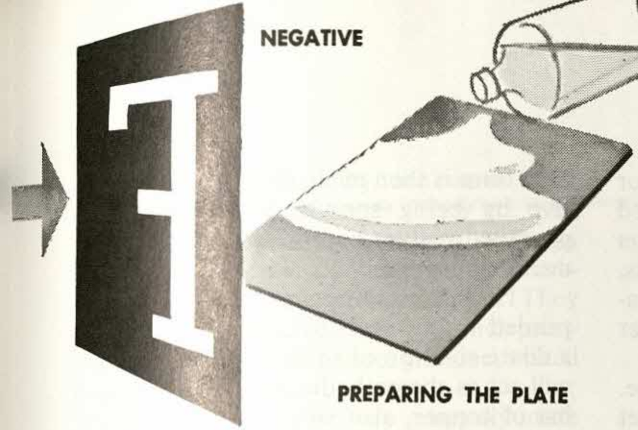
In order to produce a plate that is suitable for printing, one must break up a continuous-tone illustration such as a photograph into a series of tiny dots that vary in size and shape. This is done by placing a screen in front of the photographic plate. *A*, below, shows a continuous-tone pattern. In *B*, we see the pattern reproduced on paper that has been printed from a halftone photoengraving. The different tones are rendered by a series of dots, which are shown greatly enlarged here in order to demonstrate what they look like.



The process of preparing letterpress printing plates from photographs and drawings is called *photoengraving*. First, a photograph of the artwork is taken with a large camera. Photographs and other varying-tone materials are photographed through a *halftone screen*. This is made up of two sheets of glass, each containing a series of black opaque parallel lines. The sheets have been cemented together, with the lines of one at right angles to the lines of the other, thus forming a grid pattern. The screen is set in front of the photographic plate in the camera. It causes the reflected light to be broken up into dots. These depend for their size and pattern on the intensity of the light reflected from each area of the photograph. Linework is photographed without a screen.

The film is developed in the ordinary way. Several different negatives are usually stripped together on a large piece of glass, called a *flat,* for economical production.

In the meantime, a plate made of metal has been made sensitive to light. The flat of negatives is placed against the sensi-



Washing the plate with water removes the softer parts of the coating. The plate is then sprayed with acid. This removes metal in the different areas that are not to be printed. One can make a finished plate type-high by mounting it on a wooden block, as in drawing, or a metal base.

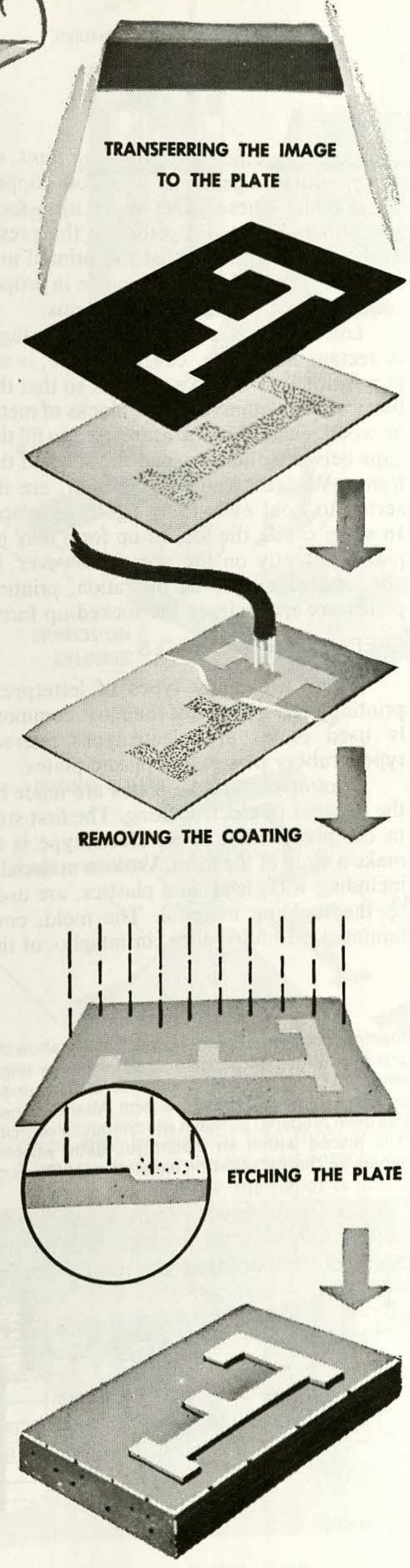
tized plate and exposed to controlled light. The light penetrates the clearer areas of the negatives—the future printing areas—and hardens the coating in the corresponding areas of the plate. It does not penetrate the dark areas of the negative, and the coating on the plate in these areas remains soft. The soft places in the coating are washed away in a water-bath, which exposes the underlying metal. The hardened places are not affected. The plate is now ready for etching.

In the etching procedure, a solution of nitric acid is used to attack the exposed metal, but not the printing surface, which is protected by the hardened coating. Etching is continued until it is deep enough for a good printing plate. The plate is then sent to the finisher who corrects any imperfections and cuts the plate, containing several different subjects, into individual plates, called *cuts*.

MAKE-UP AND LOCKUP

Make-up. The next step in the printing process is *make-up*. In this operation, type and engravings are brought together to conform to the layout that had previously been prepared. The make-up man counts the proper number of lines of text required for each page, inserts the appropriate cuts, and adds folios, or page numbers. Page proofs are then pulled.

Imposition. In the imposition process, the printing material for a number of pages



is brought together on a *make-up bank,* or *stone,* which is generally a smooth-topped metal table. These pages make up a *form* and will be printed together in the press. They are so arranged that the printed material will later fold with the pages in proper sequence and with accurate margins.

Lockup. Next comes the lockup stage. A rectangular frame, called a *chase,* is set in position on the make-up bank so that the form will fit within it. Large blocks of metal or wood, called *furniture,* are used to fill the gaps between the form and the sides of the frame. Wedges, known as *quoins,* are inserted to hold everything tightly in place. In some cases, the locked-up form may be placed directly on the press. However, in any extensive printing operation, printing plates are made from the locked-up form.

PREPARATION OF PLATES

There are many types of letterpress printing plates. Some of the most commonly used plates are electrotypes, stereotypes, rubber plates, and plastic plates.

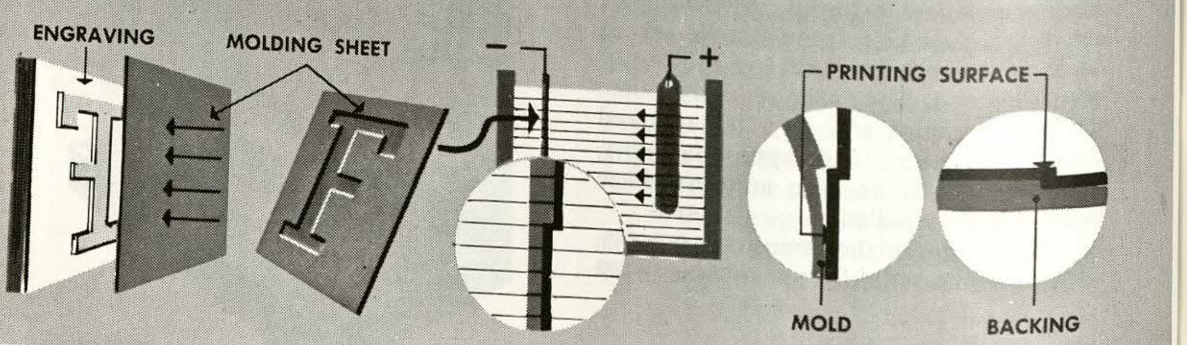
Electrotypes. These plates are made by the process of electroplating. The first step in the preparation of an electrotype is to make a mold of the form. Various materials, including wax, lead, and plastics, are used as the molding material. The mold, containing a faithful replica, in intaglio, of the type form is then made electrically conductive by being sprayed or covered with graphite, a silver compound, or other conductive material.

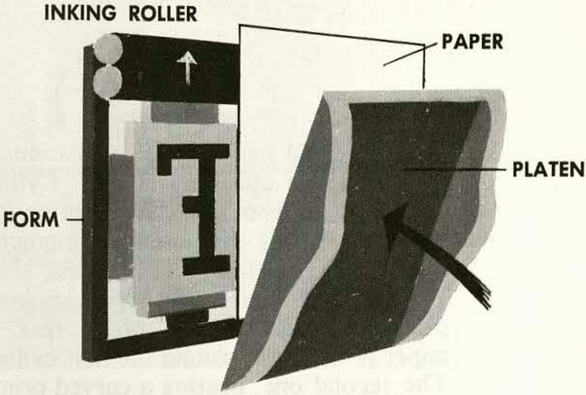
The case containing the mold is suspended in an electrolytic bath, containing a dilute solution of sulfuric acid. The mold will act as the cathode, or negative pole. A bar of copper, also suspended in the bath, will be the anode, or positive pole. When electricity is passed through the bath, copper from the bar is deposited on the mold by the process of electrolysis, forming a metal shell.

The shell is separated from the case. Since it is very thin, it must be given a solid backing, supplied by molten metal poured over the back of the shell. The finished plate is about 0.4 centimeters thick.

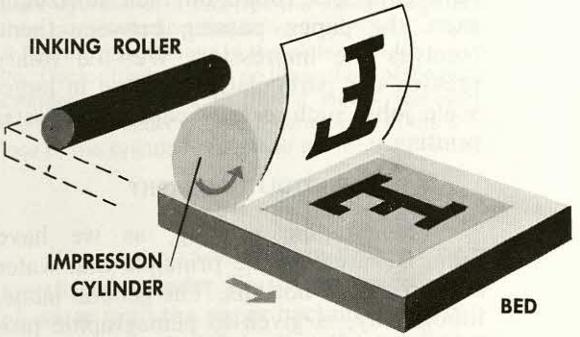
Stereotypes. To make a stereotype, a wet papier-mâché mat is first placed on the form and subjected to heavy pressure. It is dried while under pressure and gives a mold of the form. Molten type metal is poured into the depressions in the mat and makes an inexpensive duplicate of the original. If there are to be long press runs, the stereotype may be electrolytically plated to give it added hardness. Large newspapers rely almost entirely on papier-mâché mats to produce their numerous press plates rapidly and cheaply.

Electrotypes are prepared from forms. To show the process more clearly, the diagram uses the single letter *F*. First, a molding sheet is applied under pressure to the surface of the form. After this sheet has been prepared so that it will conduct electricity, it is placed within an electrolytic bath, where it serves as the cathode, or negative pole. Then, in the bath, the mold receives a thin coating of metal from a copper bar which serves as the anode, or positive pole. When enough copper has been deposited, the newly formed copper shell is removed from the mold. Molten lead is poured over the back of the shell, providing a solid backing. The finished printing plate is about 0.4 centimeters thick.

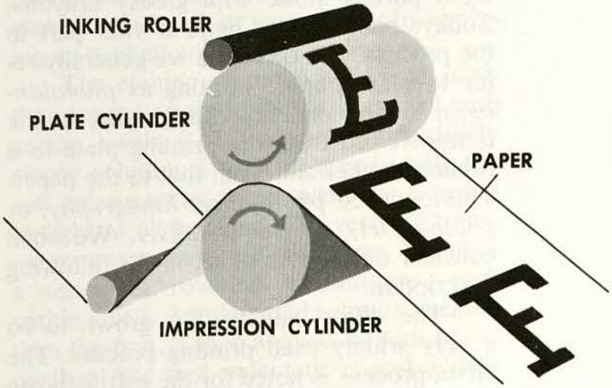




PLATEN PRESS



CYLINDER PRESS



Rubber plates. They are made from molds of the original forms. They are used principally for printing inexpensive books or business forms, containing no illustrations and using inexpensive paper. They can also be used effectively with such printing mediums as cellophane, glassine, waxed paper, cloth, and parchment.

Plastic plates. They are generally made from pattern plates: that is, electrotypes of the original form, especially made to serve as originals for duplicate plates. First, an intaglio plastic mold is produced from the pattern plate. The plastic relief plate is then made from the intaglio mold. Plastic plates are also frequently made from locked-up pages of type, and have been replacing electrotypes as printing plates.

Plates of plastic or metal can also be produced by electrical scanning devices. The stylus used in the scanning operation either burns or cuts metals or plastics, forming a series of dots or lines, varying in size or width with the density of the tone being scanned. Some of these machines can produce a printing plate that is larger or smaller than the original copy. Stylus-engraved plates are used primarily to convert continuous-tone copy to halftone printing plates. They are employed chiefly by small-scale printing plants.

PRESSWORK

In the printing presses used in letterpress, ink is applied by rollers to the face of the form or printing plate. The paper is then pressed against the plate either by a flat surface or by a cylinder, known as the *impression cylinder.*

The impression cylinder is generally made of steel and its printing surface is covered with backing sheets of special Manila paper, stretched tightly around the cylinder. In a process called *make-ready,* adjustments are made so that the form is exactly level.

Paper is fed to the press in various ways. In *sheet-fed presses,* the paper is delivered to the printing area in the form of sheets. In *web-fed presses,* it is fed as an uncut web, or roll.

The hundreds of different models of presses may be divided into three principal types: platen, cylinder, and rotary.

In the *platen press,* the paper is placed on a flat surface—the *platen*—which is brought in contact with the flat printing plate. There are many kinds of platen presses. Platen presses serve principally for small printing jobs, such as the preparation of programs, handbills, tags, tickets, and the like.

In the *cylinder press,* the paper is wrapped around a cylinder, which brings it in contact with the printing form, set on a flat horizontal bed. There are various arrangements of cylinder and bed. Cylinder presses are favored for fine printing jobs, such as books, high-quality commercial work, and limited-issue magazines.

Two cylinders are involved in the printing operation in the *rotary press*. The paper is wrapped around the first cylinder. The second one, bearing a curved printing plate, is in contact with the first one. As both cylinders rotate on their horizontal axes, the paper, passing between them, receives the impression. Web-fed rotary presses are particularly effective in large-scale jobs, such as newspaper and poster printing.

PHOTOLITHOGRAPHY

Planographic printing, as we have seen, is based on the principle that water and grease do not mix. The general name, lithography, is given to planographic processes. In earlier days, to reproduce a picture by lithography, the image was drawn on a porous stone with greasy crayons. Today, photography plays a vital part in the process, and therefore we generally refer to planographic printing as *photolithography*. In most photolithography, the ink is transferred from the printing plate to a rubber blanket and from that to the paper. This is called *photo-offset lithography*, or *photo-offset*, or simply *offset*. We shall consider only photo-offset in the following description.

The offset industry has grown to be a very widely used printing process. The offset process is noted for the soft, delicate colors it produces on textured papers. Yet it is also capable of brilliant reproductions.

PREPARATION OF OFFSET PLATES

Type matter is set as in letterpress. Proofs are pulled and corrected, and the corrected proofs serve in the making of the offset plate. Both the text matter and the art work, if any, are photographed.

After the text matter and illustrations have been photographed, the negatives are assembled, according to the layout, on a sheet of transparent acetate. Large areas which are not to be printed are masked by hand with an opaque fluid. The acetate sheet is then placed over a large, pliable metal plate, which has been specially prepared. It has been given a grain so that it will receive water and it has been covered with a light-sensitive coating.

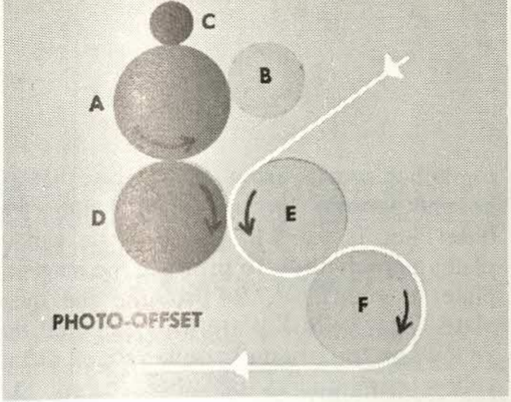
The acetate sheet is now exposed to bright light. The coating in the parts of the plate corresponding to the clear areas of the negative (the future printing areas) is hardened. In the other parts of the plate, the coating remains soft. A greasy ink is now applied to the plate. The soft areas are washed away in a water bath. These areas will receive water and will not take the greasy ink that is used in offset press work. The ink remains fixed in the hardened areas of the plate, which will constitute the printing surface.

PRESSWORK

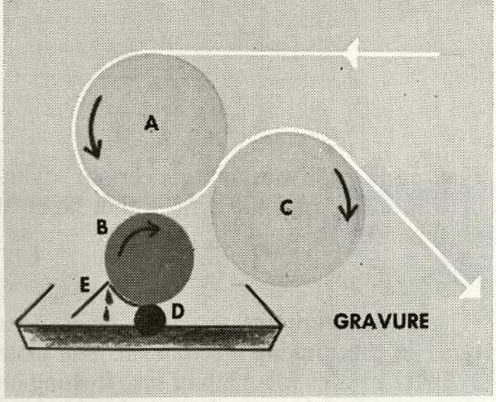
In photo-offset printing, three cylinders are used. The pliable printing plate is wrapped snugly around the first cylinder, and the top and bottom edges of the plate are locked in a slot in the cylinder. Since the printing action of the plate is based on the resistance of a greasy ink to a moist surface, the plate must be dampened as it rotates. Rollers then apply ink to the rotating plate. It comes in contact with the middle cylinder, which has a rubber cover, or blanket. The ink is transferred from the plate to the blanket. It is then applied to the paper, which passes between the rubber blanket and the third cylinder – the impression roller.

INTAGLIO

For many years, intaglio plates – plates with the printing surface etched or carved below the surface of the plate – were made by hand. Today, photographic principles are applied, and the intaglio process is called *gravure*. Its use has increased greatly in long-run publication work and in the printing of packaging. Gravure is noted for its rich, fine-screen reproduction, which has the appearance of a continuous tone. Since a great amount of ink can be drawn from the printing cells, excellent results may be obtained on in-



In photo-offset printing, shown above, the printing plate, which is wrapped around cylinder *A*, is dampened with water by roller *B* and inked by roller *C*. The printing plate comes in contact with a rubber blanket around cylinder *D*. There the ink is transferred from the plate onto the blanket. The paper that is to receive the copy is printed as it passes between the ink-bearing blanket and the impression cylinder *E*. Delivery of the paper is then made by transfer roll *F*.



In gravure printing, the sheet of paper instead passes between the impression cylinder *A* and the plate cylinder *B*. It receives the inked image and then passes around the delivery cylinder *C*. Roller *D* fills the indentations in the plate cylinder *B* with ink. Doctor blade *E* rests on the surface of the plate cylinder and scrapes ink from it, leaving the cylinder smooth and dry. The indentations in the surface of the cylinder retain their ink for the printing.

expensive paper. A disadvantage of the process is that the type is sometimes not so sharp as in letterpress or photo-offset.

The great bulk of gravure work is done in web-fed rotary presses and is called *rotogravure*. We shall consider only rotogravure in the following paragraphs.

PREPARATION OF PLATES

The type for rotogravure plates is set as in letterpress and photo-offset work. Proofs are pulled of the type matter, and these proofs are photographed together with the art work that is to be used. After the negative has been developed, a positive transparency is made from it.

A special paper called *carbon tissue* is used in the preparation of the rotogravure plate. It has a coating of gelatin, which has been dipped in dichromate solution to make it photosensitive. The positive transparency is laid over the gelatin and is exposed to a bright light. The areas which are clear in the transparency allow light to pass through and the gelatin under these areas is hardened. The other parts of the gelatin, which are the future printing areas, remain soft in varying degrees, depending on the darkness of the overlying transparency. A strong light, passed through a screen in a separate exposure, breaks up the image on the carbon tissue into a series of cells of equal size.

The carbon issue is now placed on a moistened cylinder. This is rotated in a bath of water until the paper backing of the carbon tissue peels off, leaving the gelatinous coating on the cylinder. The cylinder is now ready for etching. Large areas not to be etched are staged, or painted out, by applying an asphalt solution by hand.

The etching solution, ferric acid, is either poured on the cylinder or applied with cotton swabs. At first, a comparatively strong solution is used. It attacks only the soft gelatin areas, which were not exposed to light at all because the overlying transparency was dark in these places. It makes a series of rounded indentations, each within a cell. Another acid solution, weaker than the first, is then applied. It adds to the depth of the first indentations and adds a new series of indentations, where the gelatin was exposed to the not-quite-so-dark parts of the transparency. As many as five other acid baths are applied, each one weaker than the last. The cells that are etched out all have the same diameter but vary in depth, depending on the length of time they have been exposed to the acid. The deeper the etching in the cell, the more ink it will hold and the darker the tone it will print.

Proofs are run off from the etched cylinders and are carefully studied. Additional work is then done by hand on the cylinders.

For additional durability, certain cylinders are electroplated with a thin layer of chromium.

PRESSWORK

Rotogravure presses differ from other types in their inking mechanism. The plate cylinder rotates in a bath of ink. Resting on the surface of the cylinder is a thin blade of steel, called a *doctor blade*. It scrapes the ink from the surface, leaving it smooth and dry, while the cells retain ink. As the cylinder rotates, paper is pressed firmly against the cleaned portion of the cylinder by a second cylinder—the impression roller. Ink is then drawn from the cells onto the paper by capillary action.

COLOR PRINTING

In all three major printing processes, various colors can be applied to paper simply by changing the color of the ink in the fountain. If the differently colored inks are not printed one over the other, the process is called *flat color printing*. The plates used in the process must be correctly positioned, so that color appears *in register:* that is, in the desired place.

One cannot use flat color printing in reproducing paintings or color photographs, where many varying shades of color are found. For such work, the technique known as *process color printing* is employed. It consists of printing one color over another so that there is a blending of colors, producing a variety of shades. An exact reproduction in process color work is impossible. However, by exercising great care, beautiful approximations of paintings or color transparencies can be obtained in the three major printing processes.

The colors of ink used in process color printing are yellow, magenta, and cyan. Theoretically, these three colors in varying combinations can produce all desired shades of color, including black. Most process color printers use a fourth color—black usually—to give accents and depth to the reproduction.

The preparation of process color printing plates, for all three printing processes, begins with color separations. The photographer works from color copy, which he photographs through special filters. A blue filter is used to produce the yellow plate; a green filter, to produce the magenta plate; a red filter, to produce the cyan plate. The yellow plate will print all the yellows in the original copy, as well as the yellow components of other colors. The magenta plate will print the magenta elements in the original; the cyan plate, the cyan elements. The black plate may be prepared from any one of the color separations, or from a combination of the color separations. Unfortunately, the filters do not separate the colors accurately. Much tedious correction by experts is required.

After the plates have been prepared, proofs are pulled and corrections are made by hand. Throughout the printing operation, the slightest variation will affect the quality of the reproduction. Much will depend on the viscosity of the ink and the amount applied to each plate on the press. The plates must be kept in accurate register. In the printing press, the paper is first imprinted with the yellow plate and then in turn with the red, blue, and black plates.

SOME SPECIALIZED PROCESSES

Various specialized printing processes are in use throughout the world. Three of these are worthy of mention here. *Flexographic printing,* a relief process, uses rubber plates to transfer a quick-drying aniline dye to paper or cloth.

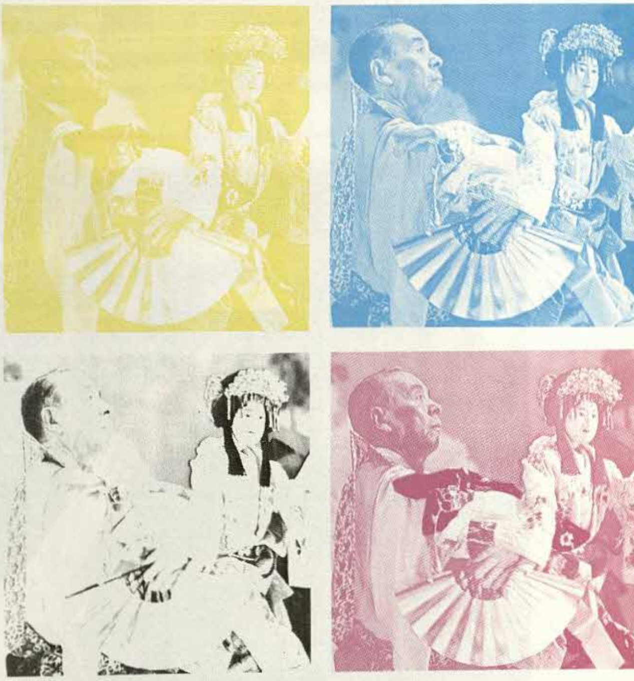
In *silk-screen printing,* colored inks are transferred through a tightly stretched silk screen onto paper, cloth or other material. Thus, a stencil containing the design is first prepared. The ink is then forced through the open places in the stencil and through the meshes of the silk screen onto the printing medium. Brilliant color effects can be produced with this technique.

Xerography is a dry electrical printing process. The ink is in the form of a negatively charged powder, which is dusted on a positively charged printing plate. The powder seeks out the areas that are to be printed because these are more heavily charged than the other areas. The powder on the electrified plate is then transferred to paper. When the paper is heated, the ink becomes fused, creating a permanent image on the paper.

BINDERY WORK

The many and varied finishing operations that follow printing are performed in the bindery. Usually the printed sheet must be folded and then trimmed. Publications such as books and magazines are generally printed in groups of pages. When the pages of one of these groups are folded together, they form a *signature*, which may contain from four to sixty-four pages. The number of signatures depends upon the size of the book or magazine and also upon the number of pages in each signature.

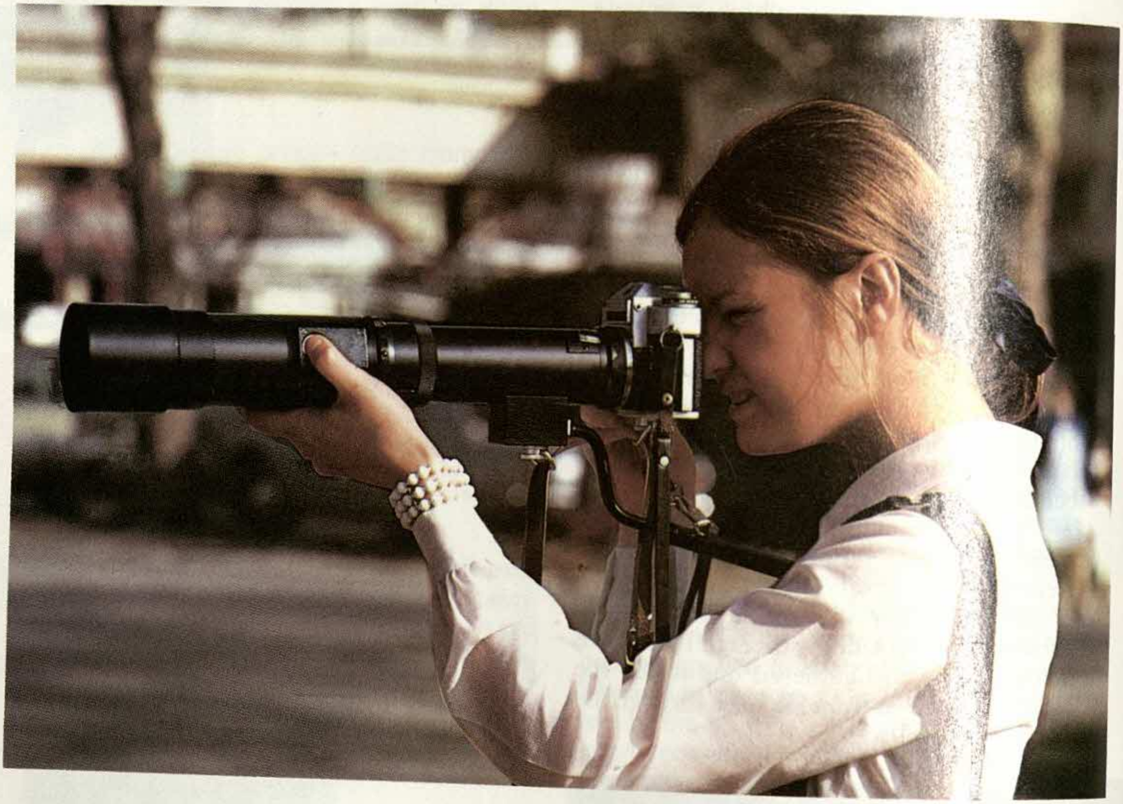
The signatures are *collated*, or gathered together, in proper sequence to complete the publication. They are then stapled or sewn together in various ways. Some publications are saddle-stitched: that is, the folded sheets are gathered one inside the other and stapled from the back through the center fold. Larger books and magazines are collated with one signature on top of the next. They are then stitched completely through the side from front to back, or sewn through the center of each signature, with the thread joined at the backs of the different signatures.



Himma—Ziolo

Michel Cambazard

The ink colors used in process color printing are: yellow, a shade of blue called cyan, and a shade of red called magenta. Theoretically, in varying combinations, these three colors can produce every other shade desired, including black, but commonly black or some other fourth color is added to give accents and depth. A color press, such as the one shown at left, combines the four colors shown above.



Guy Gillette/Photo Researchers

PHOTOGRAPHY

by Barbara Lobron

Photographs are the threads that tie together the moments of our lives. Most of us have been posing for, gazing at, and taking them since birth. They record the personal events—the picnics and trips, holidays, birthdays, and graduations—and help tell us the news. They advertise products and reproduce legal documents. When run together in a projector to give the illusion of continuity, they entertain us as movies. When used in the study of the breakup of atoms or to capture light that has been analyzed by a spectroscope, they aid science. Via X rays, they record the interior parts of our body; at observatories, they bring us closer to the stars.

Photographs immortalize our heroes and heroines and keep fresh forever the glance of those we love. And more and more, they are used to express our personal vision, as creative photography has become a popular art form. Its technology is making this art form more accessible to everyone.

TWO SIMPLE FACTS

Any photograph is based on two simple scientific facts: 1. Light passing through a lens forms an image. 2. Light darkens certain substances.

In photography light rays reflected from the subject being photographed pass through a lens into a light-tight box, called a *camera.* These light rays affect the light-sensitive material that is on the film, which is at the other end of the camera. In this way, an image is recorded on the light-sensitive film. Later, the image is made visible and usable when it is treated with certain chemicals. The negative image that is produced is later printed on light-sensitive paper and appears as a positive image, or a *photograph.*

The first camera dates back before the tenth century—the *camera obscura* (Latin for "darkened chamber"). This camera was actually a small room with a hole in one wall. The hole allowed the light rays reflected off external objects to enter and strike the opposite wall, forming an inverted image of the object. An artist would then trace the inverted image on the wall. The modern camera works on the same principle as the *camera obscura,* but instead of the image being reflected on a wall, it is reflected and recorded on film.

BASIC PARTS

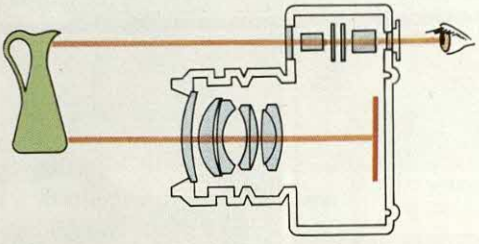
No matter how simple or sophisticated, all cameras have the same basic parts:

1. A light-tight box to keep unwanted light out and to serve as a frame to hold the other parts.
2. A lens to collect the light reflected from a subject.
3. A lens opening to control the amount of light reaching the film.
4. A shutter to control the length of time that light reaches the film. It keeps out all light until you take a picture.
5. A viewfinder, which lets you see what the camera "sees," and lets you frame your picture area.
6. A shutter release to open and close the shutter.
7. A film-advance mechanism to advance the film for the next picture.

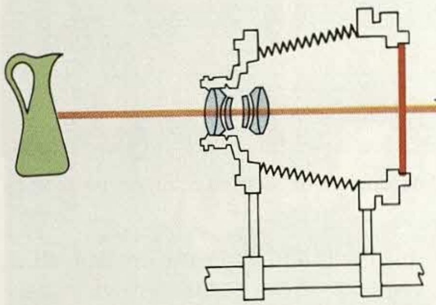
THE SIMPLE CAMERA

The simplest kind of camera is called the viewfinder camera. It uses a small window for viewing and has a fixed-focus lens. It offers very limited focusing for close and distant pictures. In this class of cameras are the old Brownies, and most of the newer pocket-sized, instant-load cameras.

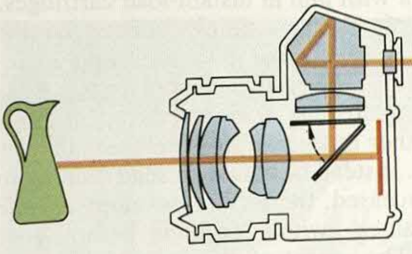
These cameras can take excellent pictures. They are not suitable for serious photography, however, because they usually lack the wide range of manual adjustments that



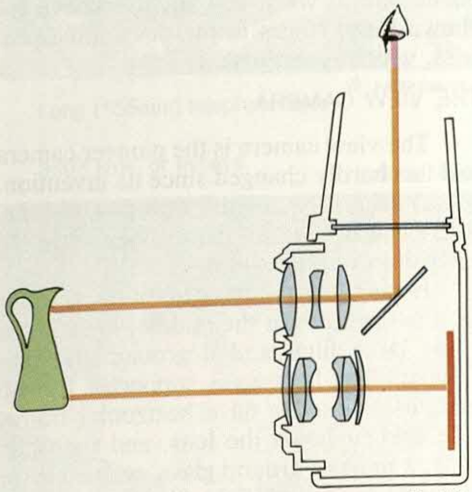
Viewfinder camera



View camera

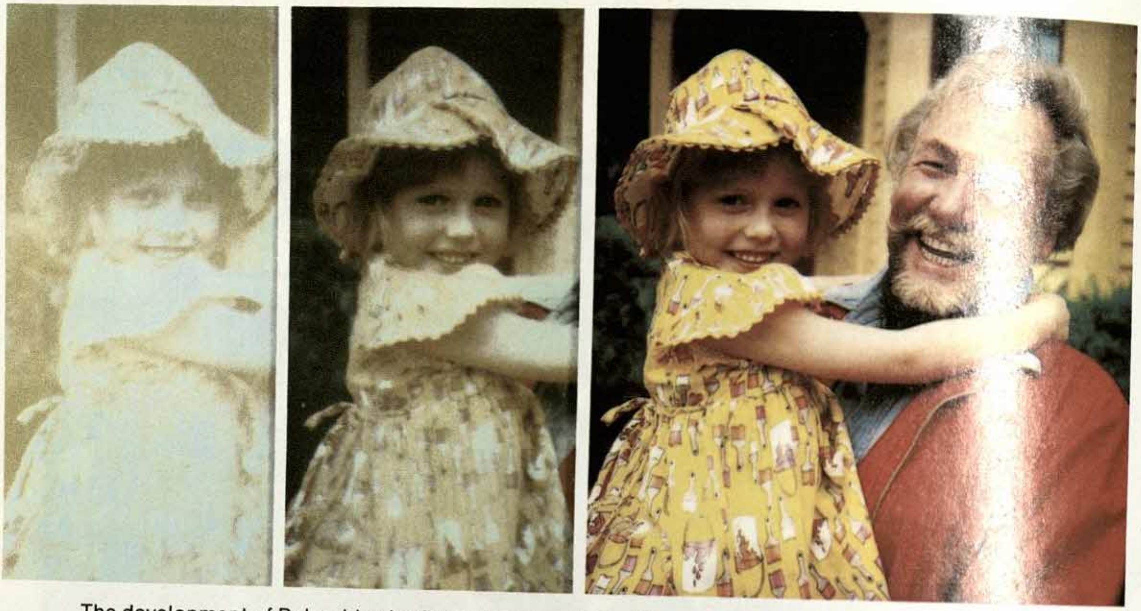


35mm single-lens reflex camera



Frank Senyk

Twin-lens reflex camera



The development of Polaroid color film takes place in the filmpack.

Polaroid

allow for focus and exposure control. Also, such cameras do not permit lens changes.

The Instamatic-type camera, introduced in 1963, is a simple aim-and-shoot camera with film in instant-load cartridges. Such cartridges are simply dropped into the camera—no manual film threading is required. An innovative camera using a disk-shaped cartridge was introduced in 1982. The other type of simple camera is the Polaroid. Instead of having to send film out to be processed, the picture develops *outside* the camera within seconds before your eyes. The secret of this camera is in the film, which is already packed with processing chemicals when you buy it. (Above are shown three stages in the developing process, which is automatic.)

THE VIEW CAMERA

The view camera is the pioneer camera and has hardly changed since its invention. It was originally called "view camera" because it was used to shoot "views" in the early days of photography.

It has a lens mounted in front, an accordionlike bellows in the middle, a back that holds large film, and a ground glass for viewing. The bellows is supported by two uprights that slide on a horizontal frame. One upright holds the lens, and the other holds a pane of ground glass, which can be replaced by a light-tight film holder when the exposure is to be made. The photographer composes his view on the ground glass, then he slides in the film when ready to take the picture.

The view camera is fairly heavy and must be set on a tripod. It is best used for panoramic views, architecture, and studio portraits. This kind of photography involves no motion. Another feature of the view camera is that it uses large film, which can be enlarged with better results than very small film.

THE REFLEX CAMERAS

The term "35-mm SLR" refers to two factors: film size and the viewing/focusing system. A 35-mm camera is one that uses film about 35 millimeters wide. SLR—which stand for "single-lens reflex"—refers to the other factor: the subject is viewed through the lens of the camera. This means that you see in the viewfinder almost exactly what will appear on the film.

The SLR has a mirror that reflects the image through the lens up into the viewfinder—hence the term "reflex." When you snap the picture, the mirror moves out of the way. This opens a path for the light to travel to the back of the camera and expose the film. The characteristic click you hear when you take a picture with an SLR is the sound of the mirror movement.

The 35-mm SLR is sometimes called a *system* camera because it offers a system of interchangeable lenses that can be used with that camera. In this way, when you look through the viewfinder, you look through the lens of your choice.

Another type of reflex camera is the twin-lens reflex (TLR). The TLR has two external lenses and a fixed mirror. The top lens, with the aid of the mirror, is for viewing. The bottom lens is for taking the picture. Viewing a subject on the 60mm x 60mm groundglass viewer is more accurate and precise than composing through a 35mm viewfinder. But the TLR is bulkier and slower to use.

LENSES

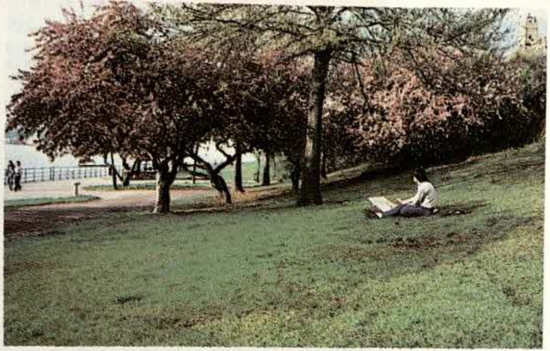
The lens is the eye of the camera. It is made of optical glass that bends light to form the image. It transmits just enough light during a set interval to make an image of the subject on the film.

The photographer controls the amount of light striking the film in two ways: 1) by controlling the length of time the light enters through the lens, and 2) by the size of the lens opening. A lens can be likened to a faucet. Just as a faucet turned on all the way lets water through faster than one turned on half way, a wide-open lens lets in more light than one that is closed down to a small opening.

A lens must be focused. Though your eyes automatically adjust, most camera lenses do not. For a sharp picture of an object, the lens must be moved to a certain distance from the film. To focus on distant objects, the lens is moved back closer to the film. For nearer objects, it is moved forward, away from the film.

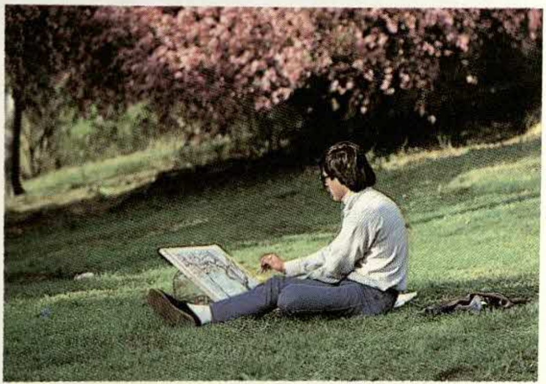
A lens is described partly by its focal length. A lens has a certain *focal length.* This characteristic is the distance the lens must be from the film to give a sharp image of a distant object, when focused at infinity.

Lenses come in normal, short, and long focal lengths. A lens with a focal length of 50 millimeters is a normal lens for a 35mm camera. It has an angle of view of about 47 degrees. When you look through the viewfinder while using this lens, you will see about what you would with your own eyes. It is this normal lens that is most often purchased with the 35mm camera.



Short (28mm) wide-angle lens

© Judith Lucretia Wright



Medium (50mm) normal-angle lens

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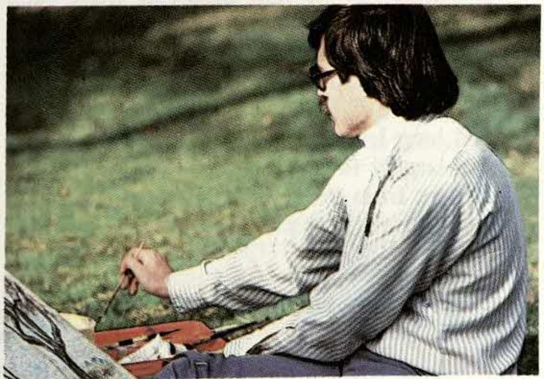
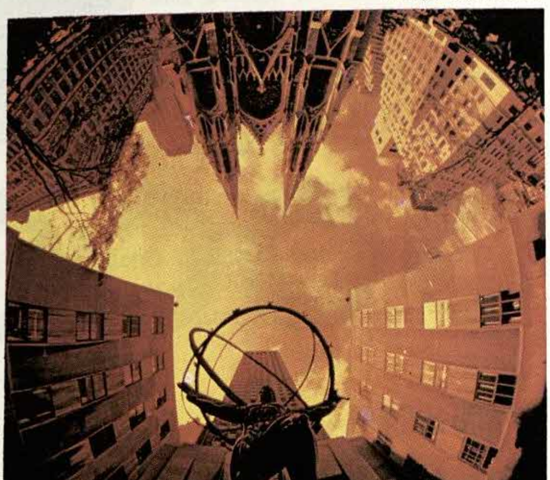


Long (135mm) telephoto lens

© Judith Lucretia Wright

360° lens, or fisheye

Hidalgo, Top Realities



The focal length of a lens is related to its *angle of view*. A lens with an angle of view much greater than 47 degrees is considered *wide-angle*. It lets you get a bigger view into the frame. Such a lens shows things small within a wide field of view. It can take in whole landscapes. The lower the mm number (focal length), the broader the horizon will be.

Long lenses act like telescopes. They have a narrow angle of view—much less than 47 degrees—and they "see things large." They produce a close-up of a distant object through magnification. It is the ideal lens with which to shoot a far-off football player or the tiger in the wilds. The bigger the mm number (focal length), the bigger the image.

THE LENS AND PERSPECTIVE

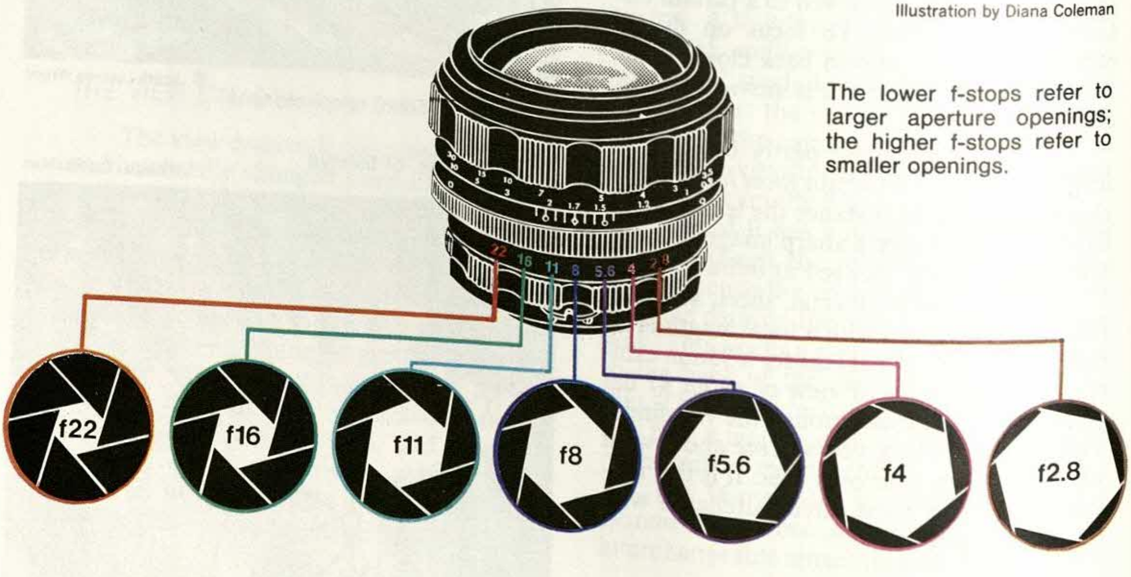
In photographing, the choice of lens determines the *perspective,* or the way things look from a given viewpoint. Perspective is concerned with the changes in apparent size of objects at varying distances from each other and the observer. A psychological notion of closeness is implied by bigness, while distance is implied by smallness.

The different ways that normal, short, and long lenses show things in pictures are due largely to the different distances of the camera from the subject. If all three lenses are used at the same position from the subject, the same view with the same perspective will appear in each picture. But a subject that fills up the telephoto picture will be smaller in the normal-lens picture and tiny in the wide-angle one.

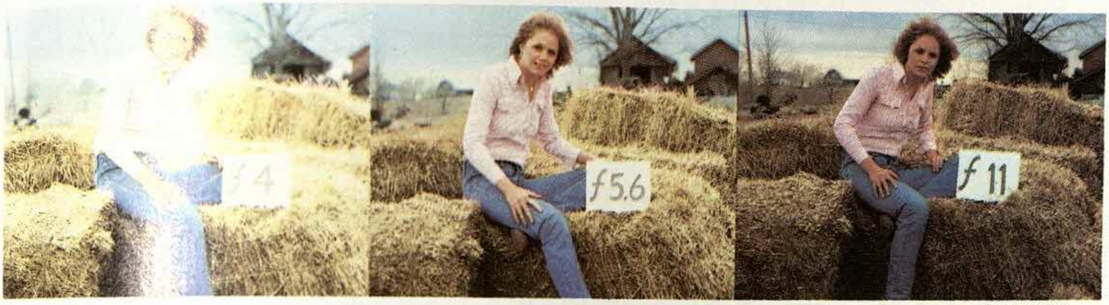
Using a normal lens to change perspective can create difficulties. For example, if you move in close to emphasize the foreground subject, you may lose a large part of the background and also distort the subject. Moving back to bring near and far objects into their proper perspective may cause you to lose touch with the subject matter in the foreground—it looks too small, too far away.

Wide-angle and telephoto lenses help with these problems. Wide angles will expand the angle of view, especially when shooting interiors. They can also make the foreground subject matter more important by letting you move in closer. The use of telephotos, on the other hand, results in a flattened perspective because the distance between foreground and background subjects appears greatly reduced. Telephotos are also used for controlling the perspective in portraiture that a normal lens would distort. For example, when you move in close with a normal lens, undue attention is focused on the nose. But shooting further back with a telephoto reduces the prominence of the nose and restores to normal the other size relationships of the eyes and ears.

Illustration by Diana Coleman



The lower f-stops refer to larger aperture openings; the higher f-stops refer to smaller openings.



AMPHOTO

Left to right: photos made with f/4, f/5.6, and f/11 openings, at same shutter speed.

We have seen that a lens is described by its focal length and angle of view. A lens is also described by its "speed." The more light-gathering ability a lens has, the "faster" it is considered to be. A fast lens is commonly used under low-light conditions. If a lens has good light-gathering ability, a faster shutter speed can be used, which will produce a sharper image with a hand-held camera. Hence that lens is considered to be "fast." The lens speed, or light-gathering ability, depends upon its diameter and its focal length.

How fast a lens is needed depends upon the light available. During daylight hours, there is enough light so that the faster lens would make no difference. Shooting indoors, as in the subdued light in a cathedral, the faster the lens, the better.

THE LENS APERTURE

In front of the lens system is a circular opening, or *aperture,* whose size determines the amount of light that will reach the film. The size of this opening is controlled by an adjustable mask called the *diaphragm.* The numbers on the lens rim indicate the relative size of the aperture. These numbers are called *f-stops.* The lower f-stop numbers refer to larger aperture openings, which expose film to more light. The higher f-stop numbers refer to smaller aperture openings, which let in less light.

Opening up means letting more light in by going from a higher f-stop to a lower f-stop. *Stopping down* means letting less light in by going from a lower f-stop to a higher one. As the aperture is opened up (higher f-stop to lower f-stop) the light that is let in doubles with each f-stop. And the reverse is true in stopping down. The following table gives the standard f-stops and relative speeds.

	f-stop		*Relative speed*
small	f/45		1X "slowest"
opening	f/32		2X
↓	f/22	↑	4X
	f/16		8X
opening up	f/11	stopping down	16X
	f/8		32X
	f/5.6		64X
	f/4		128X
↓	f/2.8	↑	256X
large	f/2		512X
opening	f/1.4		1024X "fastest"

In combination with the other exposure variable, the shutter speed, correspondingly greater exposures would have to be given. For example, if it is 1 second at f/11, it would be 2 seconds at f/16, and 4 seconds at f/22.

APERTURE AND DEPTH OF FIELD

The size of the aperture controls the *depth of field.* This is the amount of space in front of and behind the main subject that is in acceptably sharp focus. The larger the aperture (smaller-numbered f-stop) the shallower the depth of field. The smaller the aperture, the greater the depth of field.

The area in focus varies according to two other factors.

1. The camera-to-subject distance: With a particular lens set to a specific aperture, the depth of field decreases as you approach the subject. It increases as you back off to a greater distance. It also decreases if

the lens is focused closer and increases as it is focused farther back.

2. The focal length: The longer the lens (telephoto), the shallower the depth of field. The shorter the lens (wide-angle lens), the greater the depth of field.

The photographer uses depth of field for certain effects. By using "selective focus," the background can be thrown out of focus to emphasize the sharply focused subject. Where both foreground and background are interesting, great depth of field would be preferred.

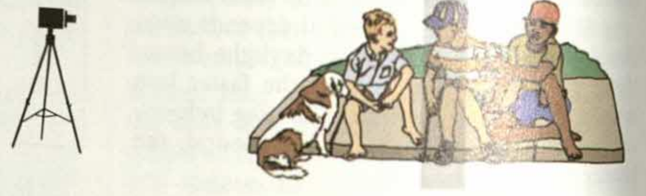
SHUTTER SPEED

The control of light entry by the aperture is only half the story. Not much could be done with a lens if there wasn't a *shutter* to let light into the camera for a certain amount of time. Like each f-stop, each shutter speed doubles or halves the exposure at the next shutter-speed setting. Standard speeds are as follows: 1 second, ½ sec., ¼ sec., ⅛, 1/15, 1/30, 1/60, 1/125, 1/250, 1/500, 1/1000. What you see on the shutter dial, however, is the denominator only—1, 2, 4, 8, and so on.

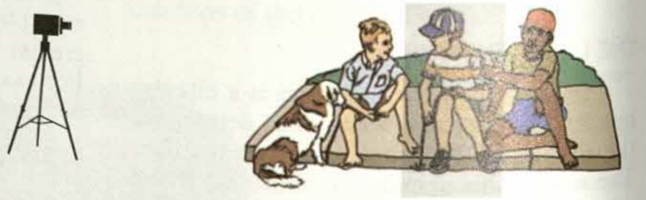
Like f-stops, shutter speeds also produce photographic effects besides controlling the exposure. A very low shutter speed shows motion through space, that is, the path of the motion. It does this more clearly than it shows the moving object. This means that the moving object will appear blurred if a slow shutter speed is used. For example, a ½-to-1 second shutter speed will show the path of movement of tall blowing grass or swaying branches.

The faster the shutter speed, the less blur. A very fast one "freezes" motion, while showing the moving object sharply. Action moving across your field of vision can also be stopped if you follow the moving subject with your camera as the shutter is pressed. This technique is called *panning.* It keeps the moving subject in focus and blurs the back-

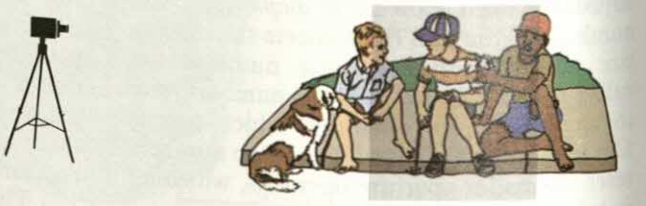
Diana Coleman



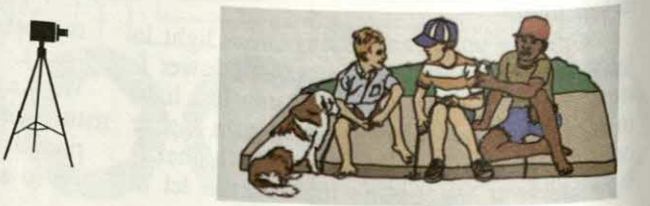
Least depth is with long lens, wide aperture, and close distance.



You get much more depth with a shorter focal length lens.



You get still more depth using a smaller lens aperture.



And you get the most depth if your subject is farther away.

© Judith Lucretia Wright

Twilight, New York City. In the evening, reds and purples prevail.

ground, which looks as though it were whizzing by. In this way a great feeling of motion is conveyed.

F-STOP AND SPEED EQUAL EXPOSURE

Exposure is the amount of light that gets to the film. It depends mainly on the light intensity and the time it is allowed to act on the film. An ideal exposure is one in which the negative film includes as much detail as possible in both the shadow and highlight areas. If too little light hits the film, it is *underexposed*. This means that the photo will be too dark. If too much light hits the film, it is *overexposed*. This means that the photo will be too light.

In setting the exposure, the photographer must decide whether the image is to be controlled by the aperture or by the shutter. When depth of field is most important, pick the f-stop first, then find a shutter speed for the correct exposure. When motion is most important, pick the shutter speed first, then stop down or open up for the correct exposure.

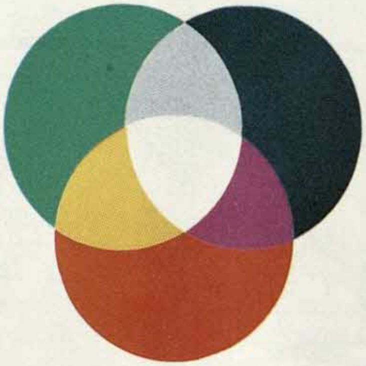
An exposure is made with the aid of an *exposure,* or *light, meter.* This is either built into the camera or separate from it and hand-held. It measures the scene's brightness in terms that can be used by the camera. The light meter contains a photovoltaic cell, which converts the light that strikes it into electric current. The brighter the light, the stronger the current. The amount of current is indicated by a moving needle, or it may be expressed as a digital readout.

Nearly all 35mm SLR cameras have built-in, through-the-lens light meters. In a camera with *match-needle* (manual) exposure control, you adjust the lens aperture and/or the shutter speed until the two needles coincide. With the more advanced 35mm SLRs, the matching is done automatically by the camera, after the user sets the aperture or shutter speed. The most recent development is one where both the shutter and aperture are pre-determined by means of a program within the camera system.

FILM

Film is a light-sensitive material that records an image. The material is made of silver and potassium salts, which are held to a cellulose-acetate base by means of a gelatin emulsion. Exposure to light turns part of the light-sensitive material darker than other parts that receive less light. The more light there is, the darker the tone.

Films are made with a specific sensitivity to light, which is called *film speed.* The



Light consists of three primary colors—red, blue, and green. When mixed, they produce white.

speed is measured on a scale originally set by the American Standards Association, hence the speeds are referred to as ASA numbers. The higher the number, the more sensitive it is to light. If a film is very sensitive, a faster shutter speed can be used with it. Therefore it is known as "fast" film. ASA ratings use an arithmetical progression—400 being twice as fast as 200 and so on.

Film speeds fall into the following groups: *slow* is ASA 32 and under; *medium* is ASA 40 to 200; *fast* is ASA 400 and over. Slow film is used when maximum sharpness and details are desired. It will highlight texture and give full contrast. Medium-speed films are excellent general purpose films, particularly when there is enough light, as in outdoor daylight conditions. High-speed films are used when there is a minimum of light.

The film's ASA number is used to key the exposure meter to existing light conditions. People who use 35mm cameras must manually set the film-speed dial on the camera to match the ASA number of the film. Those who use 110mm cameras depend on the film cartridge to automatically set the film speed of the camera.

Color-slide film comes in an ASA range of 25 to 400 and is called *transparency* film. Most color-slide film is indicated on the film box by the word "chrome" used as a suffix, as in Kodachrome.

Color prints are made with a color-negative emulsion, available in speeds ranging from ASA 80 to 400. They are indicated on the film box by the word "color" used as a suffix, as in Kodacolor.

PUSHING FILM

Both black-and-white and color films can be "pushed." This means that the film is rated and exposed at a film speed that is higher than the original ASA number set by the manufacturer. "Pushing" is usually done in order to make it possible to photograph in low-light conditions. The photographer simply sets the film-speed dial at a higher number. For example, the black-and-white film called Tri-X, which is rated by the manufacturer at ASA 400, can be pushed to a new film speed of 800 EI (EI means Exposure Index, or the film-speed rating that has been determined by the user). The photographer simply inserts the Tri-X film into the camera, and sets the film-speed dial at 800. She or he then shoots the entire role at this film-speed. When the roll of film is ready for processing, the processor must be told that the film was pushed to 800.

LIGHT

In terms of natural lighting, the main source of concern to the photographer is the sun. The moving sun during the day determines the angle of the light and the types of shadow created. The early and later hours, when the sun is low on the horizon, provide a better angle of light: shadows are long, with a soft quality, and the contrasts are soft. At midday the sun is bright, shadows are black so that contrasts are strong. Subjects are then rendered in harsh, flat tones with contrasts that are unflattering.

A similar trip through the day will show the sun's effect in a color photograph. A few minutes before the sun appears over the horizon, the color has a bluish cast. As the sun rises, the color becomes reddish. But the reds disappear as the sun reaches its zenith. Because noon sunlight is bluish, skin tones are not flatteringly rendered. As the sun begins to go down, there is a shift towards the red again. The minute the sun touches the horizon, brilliant hues of reds, blues, and purples briefly fill the sky.

A knowledge of the direction from which the sun lights up a subject is very important in photography. Here are the basic variations: *Front lighting* means the light source strikes the subject from the front—the sun is at the photographer's back. This produces a uniformly lit picture. However, it will have few shadows, which are needed to create a feeling of depth. Front lighting picks up little detail and texture, so that the picture is flat.

Side lighting means the light strikes the subject at an angle; that is, from the left or right. Side lighting reveals texture and creates a certain amount of modeling. The highlights and the larger shadows that are produced create more depth and contrast. This makes the subjects more dimensional.

Back lighting means the light source is behind the subject. This places the subject in shadow with little frontal detail. The problem in this case is to obtain an adequate exposure for the front of the subject to avoid producing a silhouette with a halo of light around it.

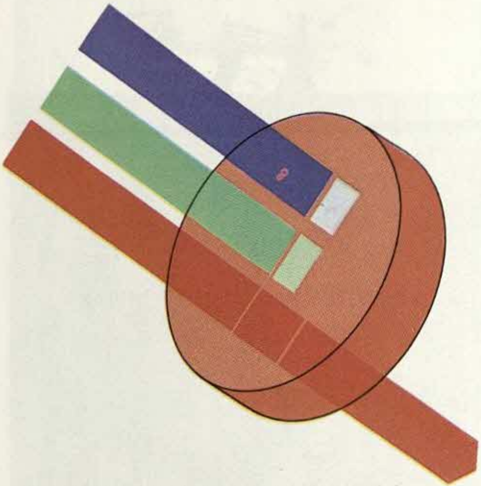
Artificial light is light supplied by something other than the sun or the moon. The electronic flash gun is most ideally suited to use with a 35mm camera. Modern cameras have built-in switches to pass an electric current to the flash gun (or flash bulb) precisely when the shutter is open.

There is a factor in the use of any artificial light source called the inverse-square law. It states that as you double the distance from the subject, the light on the subject falls off in direct proportion to that distance squared. Therefore the greater the distance you are from the subject, the greater the exposure needed.

To determine proper exposure for flash, you need to know the distance to the subject, the film speed, and the *guide number* of the flash gun or bulb (a value assigned by its manufacturer). To find the correct f-stop, the guide number is divided by the distance to the subject. For example, suppose you are using 100 ASA film, the given guide number is 250, and the distance is 15 feet. You divide 250 by 15, and get 16. Therefore, the f-stop would be f/16.

FILTERS

Black-and-white films are sensitive to all the colors that make up sunlight. In a range of gray tones, black-and-white films reproduce the light-and-dark values of colored objects more or less as the eye sees them. If you don't want to reproduce things as they look, a *filter* will change the light that strikes the film.



A filter is a colored, transparent material.

A filter is a colored, transparent material. When placed over the lens, it alters the density of color of the subject by absorbing certain colors and letting others through. A filter of any color will "darken" its complementary color in the picture and "brighten" its own color as translated into the gray tones. For example, an orange filter will darken a blue sky, and a red filter will lighten skin blemishes.

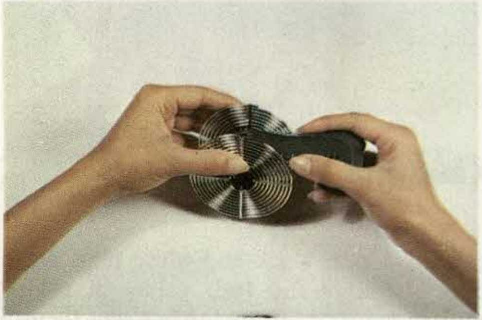
Because filters work by subtracting portions of the light from the subject, they prevent the film from receiving its full exposure. Therefore, when a filter is used, the photographer must open up the lens aperture or use a slower shutter speed. Filters have a *filter factor,* which is expressed as a number. For example, a factor of 2 requires that the exposure be doubled to get a normal negative.

DEVELOPING

The "latent image" formed during the exposure of the film has to be developed to be seen. *Developing* is the process of making that image visible and capable of being used as a negative. During a chemical process, the exposed silver salts on the film are converted to metallic silver.

After the film is removed from the cam-

Equalizing the temperature of all chemicals.



Winding film on stainless steel reel.

Pouring chemicals into film container.

Agitation of film with chemicals.

Extensive washing.

Daniel Hunter

era, it is placed in a tank, and the developer is added. It consists of one or more developing agents and other chemicals that regulate the process. The developing agents—usually a combination of Metol and hydroquinone—bring out the image. Whereas the initial light exposure determines *density,* the development process determines *contrast.* Therefore, the longer a film is left in the developer, the more contrast is built up. After it is developed, the film is rinsed in water to stop the action of the developer. It is then bathed in a fixer, called "hypo." This makes the image permanent by dissolving the unused silver salts that were not exposed. Then the film must be thoroughly washed in running water and hung up to dry.

In this way a negative is produced. It is an image in which dark stands for light and light for dark. The negative is usually not meant to be seen. It is a means to an end—the positive print.

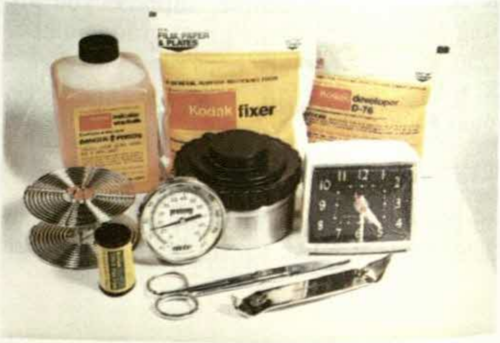
PRINTING

The print is made by passing light through a negative onto *printing paper.* Such paper is coated with a gelatin that contains light-sensitive silver salts, similar to that used for negatives, but less sensitive.

If a print is the same size as the negative, it is called a *contact print.* The printing paper is pressed tightly against the negative in a glass frame. After being exposed to the light of an electric bulb for a few seconds, it is developed, rinsed, fixed, and washed. This process is done in a series of trays under a yellow "safelight," which does not harm the emulsion.

Necessary supplies for developing black and white film. These are easy to obtain.

Daniel Hunter



Prints larger than the size of the emulsion are made by *projection.* They are enlarged by an enlarger, a device that works like a turned-around camera. Strong light is thrown on the negative, and a lens projects the negative image to any desired size on the printing paper. It is then processed in the same way as a contact print.

COLOR

If you want to know what is happening in color photography, you need some knowledge of the way colors are related. Light consists of three *primary* colors—red, blue, and green. When these are added together from separate sources, white light is created. Red, blue, and green are also described as *additive* colors because they must be added one to another to achieve an effect.

Color film is similar to a black-and-white film containing three layers of emulsion. Each emulsion layer is sensitive to only one of the primary colors. The bottom layer is sensitized to red but not to green. The middle layer is sensitized to green and slightly to blue but not to red. Next comes a yellow-dyed gelatin, which prevents blue light from reaching either of the lower levels. On top is a blue-sensitive emulsion.

During the developing process, dyes are deposited in direct proportion to the amount of exposure received by each of the three layers. Once the dye is deposited, all metallic silver and remaining silver salts are removed by bleaching and fixing. The result is a color negative.

In an enlarger, the color negative is then projected onto a sensitized color printing paper. The three primary emulsion layers of the color printing paper are in the reverse order of those of the color film. Since almost all color negatives require some kind of color correction when printed, certain filters are inserted in the enlarger's light beam to adjust the color as desired.

So far we have been referring to color-negative-to-positive print process. In the slide, or transparency, process, a positive image—not a negative—is produced at the time the film is initially developed. Kodachrome slide film consists of a piece of acetate that is coated with three emulsions sensitive respectively to blue, green, and red light. Between the blue-sensitive and green-sensitive layers is a layer of yellow dye, which acts as a filter to subtract the blue light and thus prevent it from reaching the other layers.

Gloria Laposka

Side lighting produces depth and strong contrast.

The three emulsion layers are developed to negatives, and are dyed. By special technique these three negatives are reversed to positives. The result is a transparency, which can be projected for viewing or from which a color print can be made.

FUTURE TRENDS

The direction of camera and lens development indicates ever smaller bodies, completely programmed automatic exposure, and auto-focusing lenses. Preserving color transparencies now in existence and creating new color emulsions for prints and transparencies that would prevent them from fading with age are two more challenges that seek solution in the future, as well as improvements in the present levels of technology in instant color imaging systems, both still and movie. A complete substitute for silver in film and papers is more than likely; electronic newcomers based on the principles of TV may become a viable alternative to the photographic materials and process as we know them today.

Polaroid

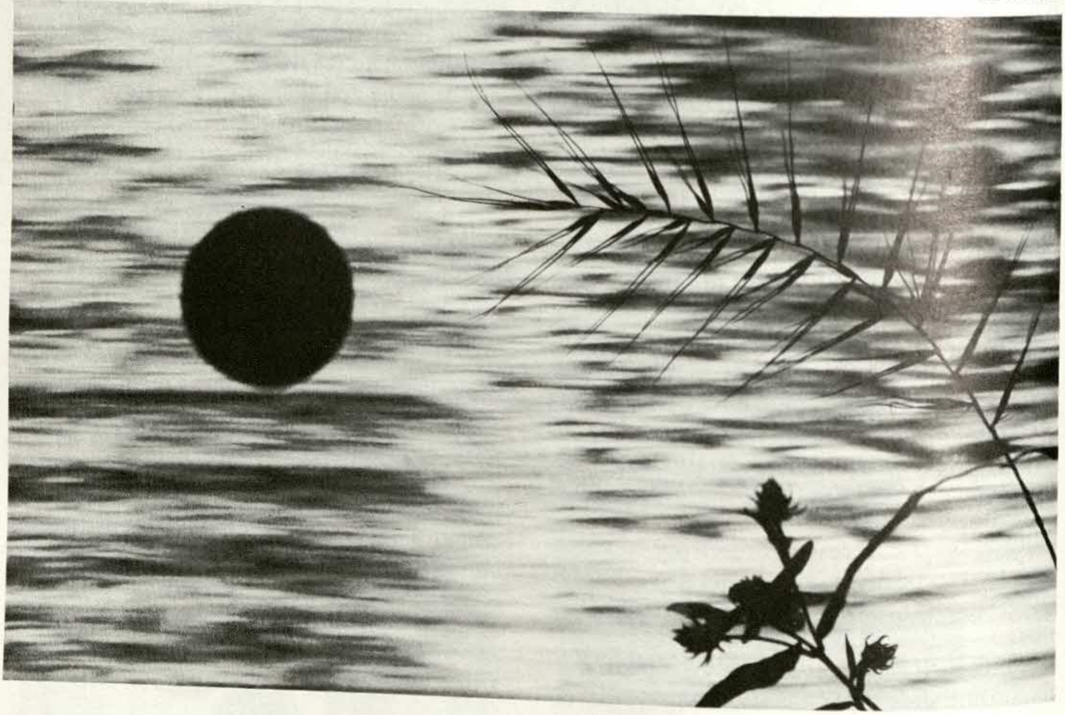
In this camera ultrasonic waves from the camera strike the subject and return to automatically focus the lens.

Some Tips For Taking Better Pictures

1. Keep your camera steady. If shooting slower than 1/60th of a second, you should steady yourself against an immovable object.
2. Have one center of interest and avoid cluttered backgrounds.
3. Including a second subject may make the photo more interesting.
4. Move in close. Get the subject in front; don't lose it in the background. Photos are more interesting if subject fills the frame.
5. Have your subjects doing something natural instead of staring at the camera.
6. Use an interesting foreground such as a tree, arch, or gate for framing your pictures.
7. Put scenes in perspective by adding people. When shooting distant scenes, people in the foreground increase the feeling of depth and size.
8. Don't always put the subject in the middle.
9. Test your view horizontally and vertically to see which way works best.
10. Use lines for interest and unity. Have natural lines, such as a road or fence, lead the eye up to the center of interest. Ver-

Often, things are not what they seem to be, especially in black-and-white photography. What looks like an eclipse of the sun, reflected in a lake, in the photo below, is actually just a "happy face" pasted on a window. The window is corrugated (wave-like) and translucent. The photo was taken inside a cabin. Light passing through the window created a back light that underexposed objects in the scene, making them appear black. Photographers often experiment like this to create impressions and moods.

Riki H. Kondo



tical lines are strong; horizontal lines are calm; diagonal lines are dynamic.

11. Be aware of background. Avoid mergers of subject and background. Get subjects away from busy backgrounds. If you can't, then open up the lens to blur the background.

12. Consider the horizon line. Don't cut your picture in half by having the horizon in the middle. A low horizon accents spaciousness, a high one suggests closeness. Make sure the horizon is level.

13. Give a moving object plenty of space in the direction it is moving.

14. Make sure that the colors and brightness of the subject and background contrast.

15. The main subject should appear brighter than anything else because the eye is pulled toward the brightest object.

16. For portraiture use a slightly longer-than-normal focal-length lens to overcome an unpleasant distortion of the subject at a close focusing range.

17. Don't lop off arms or legs because of bad framing.

18. The closer you get to your subject, the larger any part of the body will appear. If you don't want big hands and small heads, pay attention how features appear in the viewfinder.

19. The eyes are the focus of the face, so focus on the eyes.

20. Color-negative film is better if slightly overexposed. Color-reversal film is better if slightly underexposed.

21. Avoid shiny reflections by placing the camera at an angle to shiny surfaces, such as windows or eyeglasses.

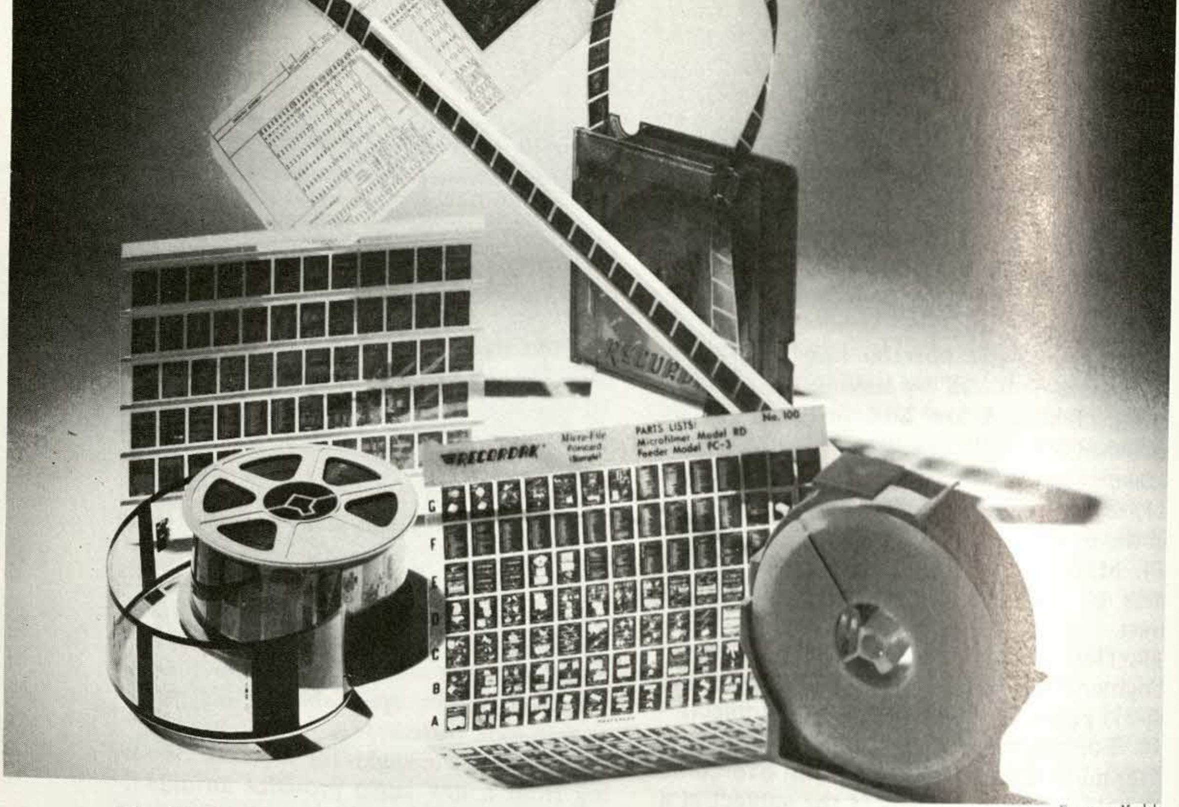
22. When using a built-in flash, keep the subject away from walls, or you will get a strong shadow on one side of the subject.

23. When the sun is bright, photograph your subject in open shade; this makes people look better.

24. Think of the angles for shooting. Shooting from a low angle provides an uncluttered sky background.

A fine example of black-and-white photography.

Barbara Pfeffer



Eastman Kodak

Microfilm is available in a great number of forms to fill a wide variety of needs. Microfilm has solved many information storage problems.

MICROFILM

by R.F. Beckwith

In 1870, when the Prussians and their German allies were besieging Paris, the inhabitants could neither receive nor send messages through the ordinary channels. Yet the flow of news into and out of the city was kept up throughout the siege because of the ingenuity of a French photographer named Dagron. He had conceived the idea of photographing messages on narrow strips of film. These were developed and flown over the enemy lines by carrier pigeons. At the destination points, the tiny pictures were projected upon walls or other suitable surfaces, or else those receiving the messages read them through magnifying glasses. To Dagron's brilliant improvisation, we owe the basic idea of microfilming, one of the outstanding duplicating developments of the twentieth century.

By microfilming we mean recording documents—book pages, letters, checks, maps, contracts, and the like—on a narrow ribbon of film. The film is developed and stored away until needed. Then it is enlarged by special reading devices.

EARLY DUPLICATORS

People have always been concerned with the problem of duplicating records. A lost will may lead to years of bickering among the prospective heirs of an estate. A lost receipt may mean endless trouble for a person. An entire community may be affected by a missing town charter. More than one business firm has been forced into bankruptcy because its records were destroyed by fire, flood, or earthquake. The only way to prevent mishaps like these is to make duplicate records, which will serve if originals are lost.

Up to the end of the Middle Ages,

S.C.E.R.T., West Bengal
Library
Calcutta
25/3, B. C. Road

duplicating of documents of all kinds, in the Western world at least, was by hand. It is said that the Chinese used movable wooden blocks to print official proclamations. In the fifteenth century, Gutenberg's invention of printing from movable type enabled men to make thousands of copies of books and other documents in a fraction of the time formerly required.

Printing has been used since Gutenberg's time for the duplicating of documents, but only when a considerable number of copies are desired. It costs as much to set type for one copy of a letter, say, as for a thousand copies. The cost of making a single printed copy would be very much higher than the cost of typing it. The duplicating methods known as *mimeographing* and *multigraphing* are also practical only when a considerable number of copies of an original are desired.

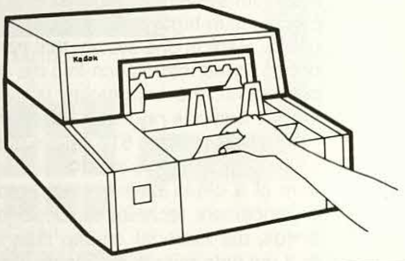
Up to a comparatively short time ago, the duplicating of records, in cases where one wished to have only one or a few copies, was entirely by hand—by writing or typing. Such duplication was time-consuming and errors sometimes crept in, for the copyist could not do his work with the accuracy of a machine.

Photocopying, or the creation of a copy on a sensitized surface by the action of light, has proved far more satisfactory. There are various photocopying methods, including the Photostat, the Verifax, the Electrofax, xerography, and smokeprinting. The thermographic method, which has become quite popular, is not, strictly speaking, a photocopying method, since it uses the heat of infrared rays, instead of light, for exposure.

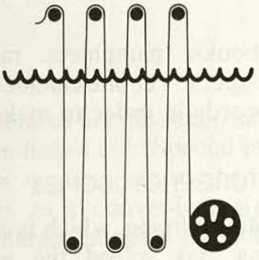
All of the copying methods mentioned in the preceding paragraph result in duplicates that take up about as much space as the original. Now the problem of finding adequate space for industrial, educational, scientific, and other records is becoming more and more acute. Government bureaus and business offices alike have been swamped with documents that in some cases have been piling up for hundreds of years. As libraries grow, they find it more and more difficult to provide shelfroom for

The four basic operations in a microfilm system

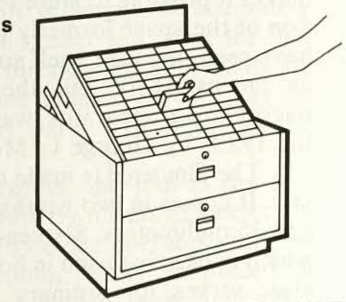
Microfilming documents



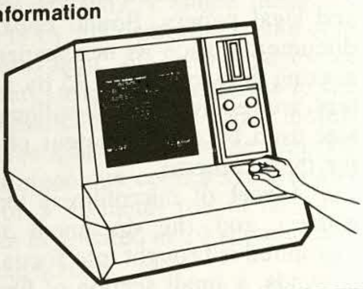
Processing film



Filing microforms

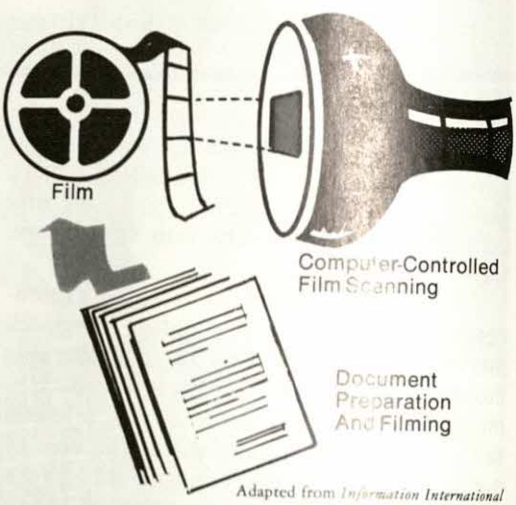


Retrieving information



Eastman Kodak

With units to carry out these basic functions, a large complex information storage system can be maintained in a relatively small area.



Microfilm systems combined with computer systems can result in highly efficient information retrieval programs. Here is one system that translates all kinds of paper-based information into the language of a computer. First, the information is transferred to microfilm. A cathode-ray tube scans the film, extracting image data in up to 512 values of gray, from black to white. The image is stored on magnetic tape, in the form of a clean binary image, produced by various enhancement techniques. Depending on the user's needs, the material on the tape can be converted and put onto microfilm, 35mm. film, paper, or a plate that goes directly onto a printing press.

Adapted from *Information International*

new books, pamphlets, magazines, and newspapers. Yet one cannot simply destroy old records in order to make way for new ones.

MINIATURE PHOTOCOPIES

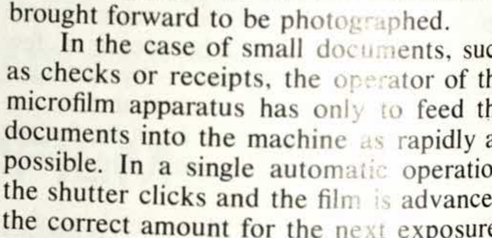
Microfilming, which is a photocopying process, has solved the problem, for it makes it possible to store records in a fraction of the space formerly required. As we have seen, the idea itself goes back at least as far as 1870; but the first practical microfilming apparatus was developed in the 1920s by George L. McCarthy.

The film used is made of cellulose acetate. It comes in two widths: 16 millimeters and 35 millimeters. Sixteen-millimeter film, which is like that used in home movie cameras, serves for ordinary business documents, such as bank checks, cards, letters, and legal papers. Bound books and large documents, such as newspapers and engineering drawings up to 95 by 133 centimeters, are recorded on 25-millimeter film, the size used by many amateur photographers for their cameras.

A reel of microfilm is loaded in the camera and the document to be photographed is brought into focus. As the roll unwinds, a small section of film is brought into position opposite the camera lens. An exposure is made. Then that bit of film is wound away from the lens, a new section takes its place, and another document is brought forward to be photographed.

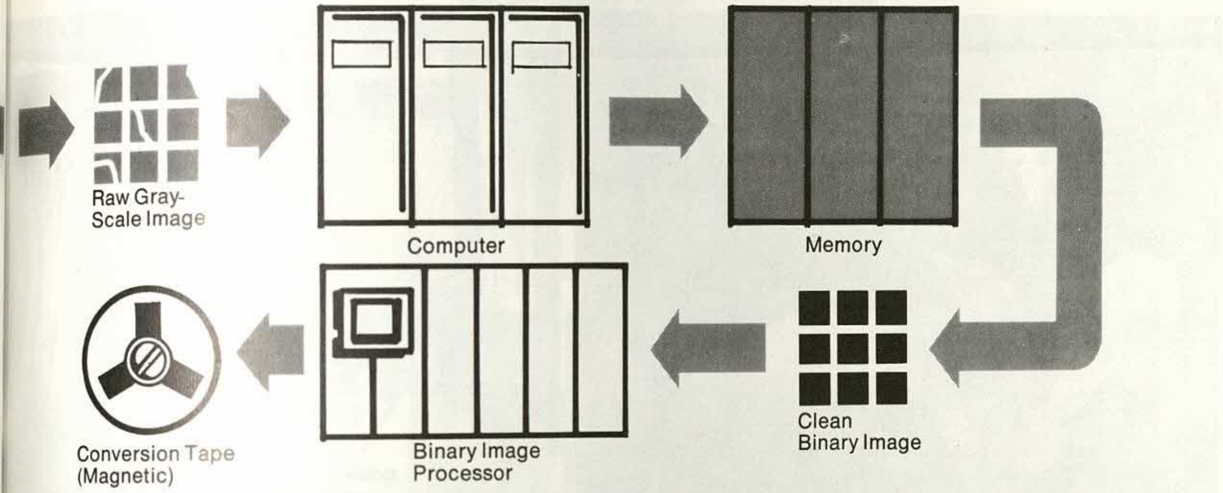
In the case of small documents, such as checks or receipts, the operator of the microfilm apparatus has only to feed the documents into the machine as rapidly as possible. In a single automatic operation the shutter clicks and the film is advanced the correct amount for the next exposure. Focus, light intensity, distance from lens to subject, diaphragm opening—all are fixed and require no adjustment.

Large documents are laid on a flat surface and photographed by a special camera unit that can be raised or lowered on a supporting platform. Bound volumes can be photographed without removing the bindings. For this purpose the machine is provided with a mechanical book cradle



In the system shown above, a raw gray-scale image (left) is converted to a "clean" image with constant line width (right).

**Editor's note:* The drawings and diagrams in this article were adapted from material supplied by the *Life* picture collection, the Minox Corporation, the Recordak Corporation, the United States Army (Technical Manual 12-257) and the United States Department of Justice.



that automatically brings the individual pages in turn beneath the camera lens. It is possible to photograph two pages simultaneously. Before the exposure is made, a beam of light is projected downward and outlines the exact area that is to be photographed. In this way, only the precise amount of film required is used for each exposure.

When the reel of film has been entirely exposed, it is removed from the camera and developed. We now see on the film a series of tiny images, separated from each other by a narrow border. Each image is greatly reduced from the size of the original: a document 25 centimeters square can be reproduced on 0.7 square centimeters of microfilm.

When the film is developed, it is in the form of a negative. This mean that what is dark in the original is light in the negative and vice versa. Generally the developed film is left in negative form. It is wound on a reel and enclosed in a cardboard box. If a roll contains a number of unconnected items, it is sometimes cut into comparatively short lengths, which are placed, flat, in long, thin envelopes or transparent plastic jackets and stored in labeled boxes or filing cabinets. Sometimes cut film is placed in cloth pockets, sewn on the backs of filing cards. The cards are stored in ordinary filing cabinets.

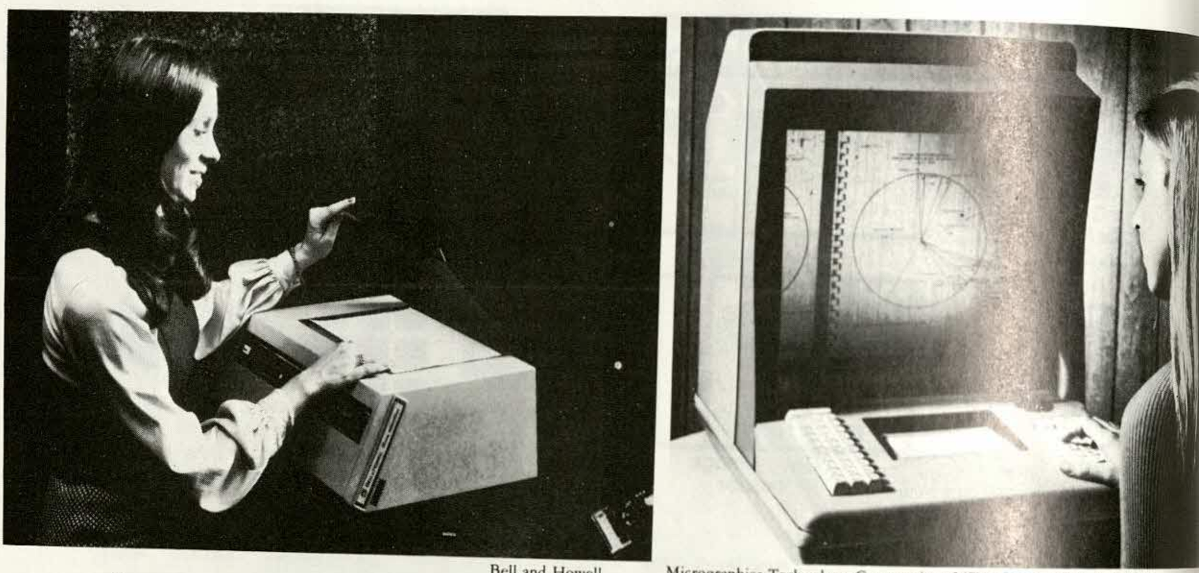
READING MICROFILM

The tiny pictures are much too small to be read with the naked eye. Special projectors, called *film readers,* are used to magnify the images to a convenient size for reading. The enlarged image is projected on a translucent screen, where every detail of the original record is clearly and accurately reproduced. The reader can work the film back and forth through the film reader by means of winding cranks. In this way he can refer to any part of the film that he wishes.

In some readers, the film is run forward and backward by means of an electric motor. One such device operates with 16-millimeter microfilm, which is placed in special containers called *magazines* after the film is processed. A single magazine measuring 11½ by 11½ centimeters can contain the equivalent of 2,400 pages of printed matter. Inserting a magazine in the reader automatically starts the motor, lights the screen, and threads the film. By means of an ingenious coding system, any given page on a 30-meter roll of film in a magazine can be located in 20 seconds and flashed on the screen.

PRINTS CAN BE MADE

Positive film prints may be made from a microfilm negative, of course. Paper prints in any size up to that of the original



Bell and Howell

Micrographics Technology Corporation (MTC) from Varian Associates

Units that produce and read microfilm have themselves been shrunk over the years. Left: a compact microfilm camera can be operated quickly and easily. Right: this modern microfiche retrieval unit gives a viewer quick access to 9,750 pages of data.

document, or even larger, can easily be produced from the negative by the ordinary photographic enlarging processes.

Blemishes may develop on microfilm after many years of storage. To guard against information loss because of such blemishes, more than one microfilm copy is often made. Prints are prepared from the negatives for the most permanent storage.

MANY ADVANTAGES

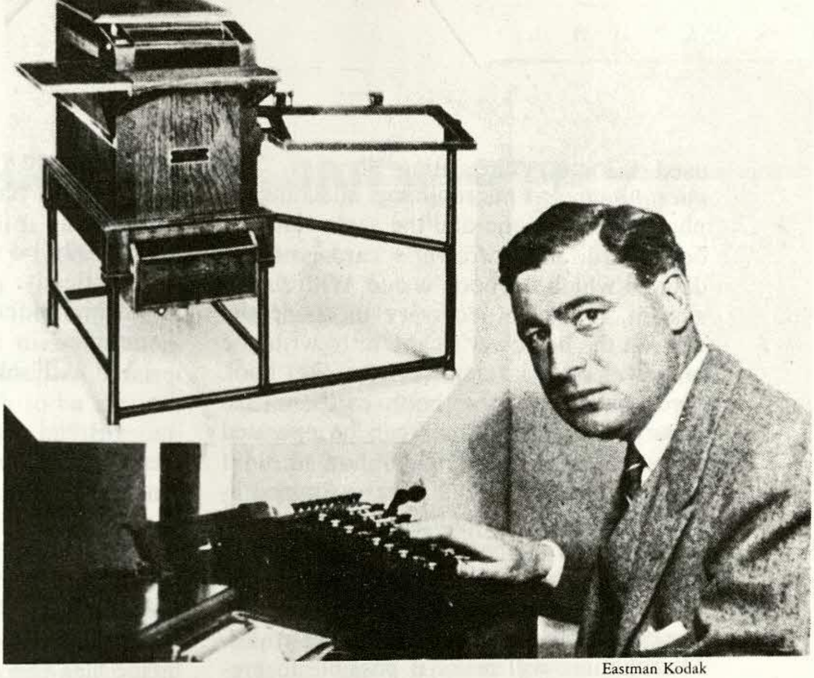
Microfilm offers many advantages over other methods of duplication. It is rapid, errorproof, and durable. According to the U.S. Bureau of Standards in Washington, D.C., microfilm made of cellulose acetate will last as long as the best grade of paper.

Perhaps the greatest advantage of microfilm is that it occupies astonishingly little space. An operator can reproduce 28,000 cards measuring $7^1/_2$ by 13 centimeters, or 10,700 $21\frac{1}{2}$-by-29-centimeters business letters, on a 30-meter roll of 16-millimeter film that can be held in the palm of your hand. A 1,600-page dictionary can be reproduced on a part of a roll of film of the same size. A four-drawer filing cabinet full of microfilm reels holds the equivalent of 50,000 bound volumes of ordinary size. A single safety-deposit box in the vault of a bank could hold all the confidential records of a great business enterprise, reproduced in the medium of microfilm.

USES

Business and industry. Microfilming has so far found its widest use in business and industry. Banks microfilm canceled checks and bank statements, thus protecting both the bank and the depositors against loss and fraud. Business houses microfilm their correspondence files and their accounts-receivable records. Engineering departments record their mechanical drawings and other data. When a leading electrical manufacturer microfilmed 4,000,000 old shop orders, sketches, drawings, and charts, he saved almost one hectare of floor space.

In some instances, original business documents continue in everyday use after microfilms have been made of them, while the negatives are stored in safety-deposit boxes. In other cases, the bulky originals are destroyed, positives serving in the office or plant while negatives are stored.



Introduced in 1928, the Recordak Model 1 was the world's first practical microfilmer. While it was a good instrument in its day, it is crude and cumbersome by today's standards.

Eastman Kodak

Some business houses and factories have their microfilming done by companies that specialize in this sort of service. The camera is generally set up in the place where the records are and reproductions are made while the ordinary business of the firm is being carried on. The films are developed by the company that provides the service. Other firms rent or buy their own microfilming equipment.

Government. Federal government bureaus in the United States and Canada microfilm many of their records; so do state, or provincial, county, and municipal agencies. Quantities of old records have been recorded on microfilm and then destroyed, thus releasing valuable space.

Publishing. Picture research in the files of magazines and other publications is made easier by means of microfilming. The picture files of one large publishing company are indexed mainly by $7^1/_2$-by-13 centimeter catalogue cards. Each of these cards features a print made from a microfilm negative, and descriptive data.

Before the development of the microfilming process, libraries were seriously concerned with the problem of keeping up their newspaper files. Such files are very bulky and it is difficult to find space for them. Besides, newspapers have for years been printed on fragile sulfite and wood-pulp paper, instead of on high quality paper, with the result that many of the old newspapers in the files have crumbled away.

Nowadays a number of leading newspaper publishers are having all current editions microfilmed. Some of them have had all their old issues recorded on microfilm. Newspapers sell positive film prints to other newspapers, local libraries, and historical societies.

Libraries. Every library has a certain number of rare books and manuscripts and also books that are too badly worn to be used by the general public. Formerly, only a few people were permitted to consult them. Now a good deal of this material, in microfilm form, is available to all.

It often happened, in the past, that scholars wishing to consult rare books or manuscripts had to visit the libraries where these books or manuscripts were kept, or else they had to pay somebody to copy the contents by hand. When the photostatic method of reproduction was devedoped, scholars could have photostats made. However, the cost was far too high for the average scholar if he had to have many documents reproduced in this way. Nowadays a number of libraries are equipped to supply microfilm reproductions of any item included on their shelves or on the shelves of near-by libraries. The cost comes to only a few cents a page.

Microfilm book-charging systems are

used in many circulating libraries. The *microfilmer*—a microfilming machine—√ photographs at one and the same time the book card, the borrower's card, and the date on which the book is due. With such a system, it is not necessary to stamp the date on the borrower's card, or to write the borrower's serial number on the book card, or to file the book cards in the library. The microfilmer can be operated by clerks, who can be taught how to run it in a few minutes. This releases trained librarians for more important library work.

Special projects. Often, when we seek to learn about the civilization of past ages, we have to grope in the dark because so many ancient documents have been destroyed. Microfilming will make it possible to preserve for posterity a remarkably complete record of our own civilization and those that follow. A dramatic example of how this may be done was provided in 1939, at the New York World's Fair. The Westinghouse Time Capsule, a receptacle containing various exhibits of our civilization, was lowered into a crypt at the Fair. It was not to be opened again until 6939 A.D.—5,000 years later. Among the contents of the capsule were three and one-half reels of microfilm. On these had been photographed more than 30,000 pages of printed matter dealing with language, literature, science, government, industry, religion, entertainment—in short, a cross section of man's way of life in the year 1939.

During wartime, many valuable British manuscripts were lost. To prevent further loss, a great number of books and manuscripts were microfilmed under the direction of the American Council of Learned Societies, with the full cooperation of the British authorities. The microfilmed material dealt with a wide variety of subjects—American and European history, law, the fine arts, music, and literature. Copies of each microfilmed reel were deposited in Great Britain and in the Library of Congress in Washington, D. C.

PROGRESS

The techniques of microfilming and its applications have undergone tremendous development. It is now possible to reproduce almost any information on microfilm and display it in many ways. The contents can readily be shown in a portable viewer, automatically projected from a cassette-type film holder, coded and placed on magnetic tape in a computer, automatically printed in book or pamphlet form, and so on.

Instead of putting it on film reels, information can be photographically reduced onto small cards called *microfiche.* As many as 1,000 standard pages of print can be reproduced on a single microfiche card. In a later development called *ultramicrofiche,* up to 8,000 pages of print can go on one film card. Entire books or magazine files can be recorded on a card, with an enormous saying of library space.

Microfilm, however, is no longer used simply to duplicate printed matter. Today, journals, news, books, catalogs, and magazines may be published entirely on microfilm alone. Very often a computer is used, which speeds the printing tremendously.

Modern methods of retrieving, or extracting, information from stored microfilm and microfiche records are also very rapid, taking only a few seconds to several minutes. Computers are often applied in this task. The many advantages of these new methods makes one wonder if there will soon come a day when all books and paper records will be obsolete.

This light-weight, counter-top microfiche reader has a recessed shielded screen to eliminate eyestrain. Devices such as this may soon radically alter our concept of books.

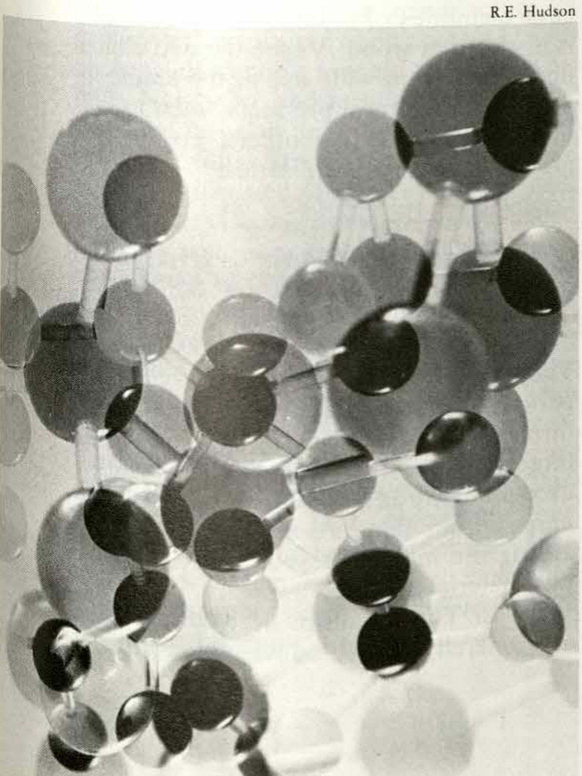
Bell and Howell

THE CHEMICAL INDUSTRY

by Anthony Standen

What is the chemical industry? One might say, I suppose, that this is the industry that makes chemicals, but such a definition would leave much to be desired. Just what is a chemical, after all? Presumably, it is a pure chemical substance (an element or compound) and not a mixture. Thus, sulfuric acid is a chemical, and the manufacture of sulfuric acid is undoubtedly a part of the chemistry industry. So is the manufacture of vinyl chloride, which reaches the consumer in the form of a great many plastic articles. But common salt and sugar, with which all of us are familiar, are also pure chemical substances. Yet properly considered, the preparation of these substances for the consumer has nothing to do with the chemical industry. Salt is simply dug out of the earth or evaporated from brine, and sugar is an agricultural product. We shall have to modify our first definition, then, to read "the chemical industry uses chemistry to make chemicals from other chemical substances."

R.E. Hudson



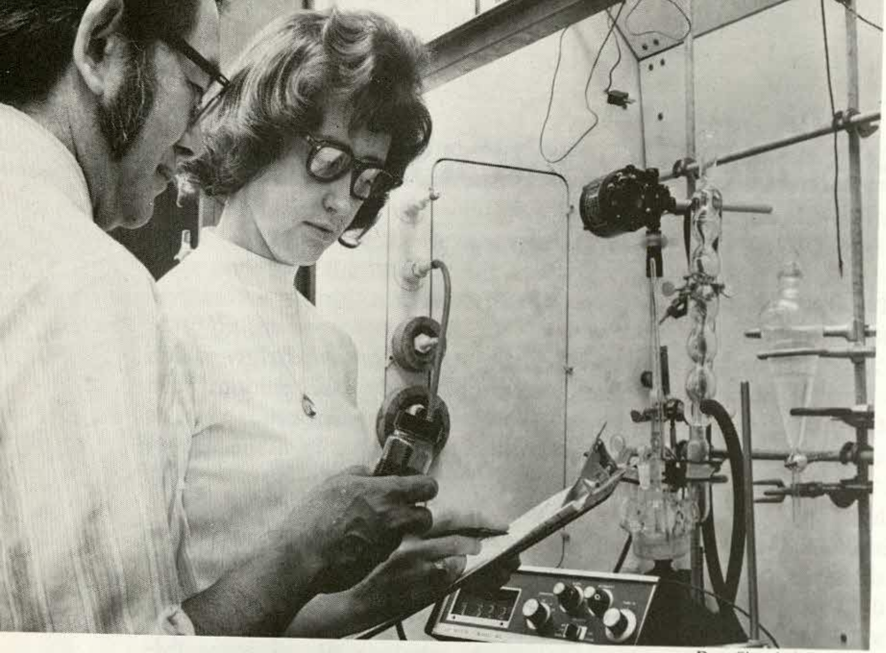
TWO LEVELS

The truly *chemical industries,* which manufacture chemicals, are seldom well known to the public. This is because we, as consumers, do not ordinarily make use of chemicals in their pure form. Instead, they are converted into products that reach the consumer only after a number of operations. Consider the chemical ethylene glycol, for example. If you drive an automobile, you are familiar with one of the products in which ethylene glycol is used—antifreeze. You would almost certainly not ask for this product under its chemical name of ethylene glycol. Rather, you would call for a particular brand of antifreeze.

The products of the chemical industries may have a number of different uses. Ammonium nitrate, for example, is used as an explosive and also as a fertilizer. A certain amount, too, goes into the production of nitrous oxide, an anesthetic used in dentistry. Hydrazine is the starting material for the manufacture of isoniazid, a drug used in the treatment of tuberculosis.

In the chemical industry, the same product may be derived from quite different sources. Ethylene glycol can be manufactured from ethylene, which is derived from petroleum. It can also be prepared from formaldehyde, which can be made from coal, air, and water, or from natural gas or from petroleum.

The part that chemistry plays in industry is by no means confined to the preparation of chemicals by the chemical industry. It is of great importance, for example, in metallurgy, which is concerned with the extraction of metals from their ores and their preparation for practical use. The metallurgical processes of smelting and refining are chemical processes. They were utilized in very distant times when the chemistry of reducing ore to metal was a trial-and-error affair, and not understood. Many other industries—glass, ceramics,



Dow Chemical Company

Before products can be marketed, they must be tested thoroughly. These research chemists are checking the manufacturing process for an insecticide.

paper, leather, beer, wine, and food, to name only a few—also depend on chemistry. All these are examples of *chemical-process industries*. They work with materials that are changed chemically in the process of manufacture, but the end product is not a pure "chemical" that will be used by some other industry. Many of the chemical-process industries are discussed in other articles of this set.

As a matter of fact, there is some chemistry in practically any industry that can be mentioned. For example, chemical processes are used in the preparation of the ink used in a newspaper printing plant. In a textile mill (quite apart from the fact that it may be using modern synthetic fibers—products of chemistry), there are many chemical operations in the sizing, scouring, and conditioning of fibers for the successive operations. We should bear in mind, too, that any industrial product has a definite chemical composition, and that this is usually a matter of importance.

THE CHEMICAL INDUSTRIES

In the preceding paragraphs, we have given a preliminary survey of the part that chemistry plays in industry. We shall now devote our attention to the raw materials from which chemicals are made. We shall tell how these materials are processed, and we shall consider a few of the uses to which the end products are put.

For very large segments of the chemical industry, the most important raw materials are coal, petroleum, natural gas, limestone, salt, and sulfur. To these may be added phosphate rock, fluorspar, and a certain number of more specialized materials. Note that these substances are all minerals. The chemistry industry proper does not at present use organic products to any great extent to make pure chemicals. However, chemical-process industries, such as the paper, textile, and plastics industries, use large quantities of organic materials. Paper is made from wood. Vegetable and animal fibers are still in wide use in the textile industry. Agricultural products, such as cellulose, soybeans, and others, go into the processing of various plastics.

FOSSIL-FUEL DERIVITIVES

The name "fossil fuels" is given particularly to coal, petroleum, and natural gas. They have all been derived from fossil organic substances—animal and vegetable. They go back one or more geological periods, and they have been transformed through the operation of a variety of natural forces. At one time, the fossil fuels were used primarily as fuels. They still serve that purpose, but they are also now reckoned among the important sources of chemical raw materials.

Coal. The chemicals derived from coal are generally a by-product of the process whereby bituminous coal is converted into coke. This process is called *coking*. It takes place in so-called by-product coke ovens, in which coal is heated in the absence of oxygen. The solid matter remaining in the ovens is coke. The gas and vapors that result from the coking are piped to special equipment, where they are made to yield fuel gas, ammonia, and coal tar.

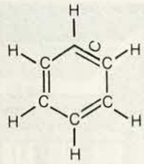
Ammonia (NH_3), a compound of nitrogen and hydrogen, is a most useful chemical. It serves in the synthesis of plastics, drugs, dyes, and many other substances. A dilute solution of ammonia in water is a well-known cleansing agent in the home. Ammonia gas is used as a refrigerant because of the ease with which it can be converted to the liquid state. Ammonia either as ammonia or in the form of ammonia products is vitally important for fertilizers.

When ammonia is mixed with air and passed over a catalyst, it yields nitric acid. Specifically, a molecule of ammonia (NH_3), reacting with 2 molecules of oxygen ($2O_2$), yields a molecule of nitric acid (HNO_3) and a molecule of water (H_2O). Or, as the chemist would put it:

$$NH_3 + 2O_2 \rightarrow HNO_3 + H_2O$$

Nitric acid leads to the manufacture of explosives, fertilizers (when combined with unchanged ammonia to yield ammonium nitrate, NH_4NO_3), and to other products.

Coal tar is an important by-product of the coke ovens. After it is piped from these ovens, it is dried, heated, and distilled, yielding a viscous liquid or solid called pitch, as well as a number of other products. Some of these products can also be obtained by stripping, or taking the substances from, the coke-oven gas. These products include benzene (C_6H_6), toluene (C_7H_8), naphthalene ($C_{10}H_8$), anthracene ($C_{14}H_{10}$), phenol (C_6H_5OH), and cresol (C_7H_7OH). They are chiefly hydrocarbons—that is, compounds made up of hydrogen and carbon. More specifically, they are known as cyclic hydrocarbons because the atoms that make up their molecules form one or more rings. Thus, benzene has the structural formula

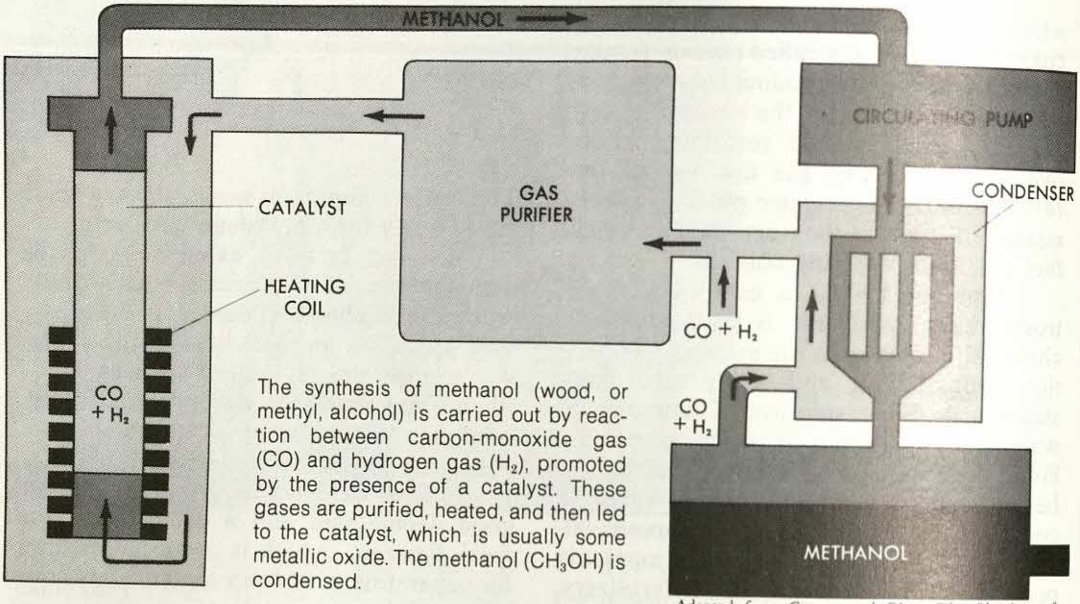


The cyclic compounds are now being made increasingly from petroleum products.

Benzene is used extensively in the manufacture of chemicals, particularly styrene and phenol. Toluene is especially well known as an ingredient in the explosive trinitrotoluene, better known as TNT. Phenol and some of its derivatives are powerful germkillers, but phenol is notably important in the synthesis of phenolic plastics. Napthalene yields various dyes. Cresol is a good disinfectant and a useful agent for *froth flotation,* which is a special method for separating ores from the minerals containing them.

Petroleum and natural gas. Petroleum is a mixture of many different kinds of hydrocarbons. They are separated by a first step called *fractional distillation.* First the crude oil is heated and converted into a vapor. Then, since the different hydrocarbons have different boiling points, they condense at different places in a tall fractionating tower and are collected separately. To refine the oil further, a number of processes may be used. In *cracking*—sometimes with the aid of a catalyst (*catalytic cracking*)—large molecules are broken down into smaller ones. This is especially important in the manufacture of gasoline. For other products, a process called *polymerization,* or building-up of large molecules from smaller ones, is used. Liquefied petroleum gas (LPG) is also one of the products of the fractional distillation of petroleum.

Natural gas often occurs together with petroleum. They are both found in the minute pores of certain rocks, including sandstone and limestone. Natural gas consists mostly of methane (CH_4), with small amounts of other hydrocarbons. In some cases it contains helium, sulfur, and carbon dioxide, which may be extracted. The gas can be processed to yield carbon black, but it is used very often as a fuel.



The synthesis of methanol (wood, or methyl, alcohol) is carried out by reaction between carbon-monoxide gas (CO) and hydrogen gas (H_2), promoted by the presence of a catalyst. These gases are purified, heated, and then led to the catalyst, which is usually some metallic oxide. The methanol (CH_3OH) is condensed.

Adapted from Conant and Blatt, *The Chemistry of Organic Compounds*

The chemicals derived from petroleum and natural gas are known as *petrochemicals.* These chemicals have become immensely important in the chemical industry. They account for about 30 per cent of the entire chemical production of the United States. They include such essential chemicals as benzene (C_6H_6), phenol (C_6H_5OH), methane (CH_4), ethane (C_2H_6), propane (C_3H_8), butane (C_4H_{10}), ethylene (C_2H_4), acetylene (C_2H_2), butadiene (C_4H_6), butylene (C_4H_8), isoprene (C_5H_8), and isobutylene (C_4H_8). These in turn yield an astonishing variety of still other fundamental and highly useful chemicals.

A rather special petrochemical product is carbon black. This substance is prepared by burning petroleum fractions or natural gas in air that is insufficient for complete combustion. Carbon black is very important as an essential ingredient in tires. It is also used, although to a lesser extent, in printer's ink.

Practically all petrochemicals have been derived from other sources besides petroleum and natural gas, and some still are derived from such sources. As we saw, such chemicals as benzene, phenol, and acetylene are still produced from coal tar. Ethyl alcohol was formerly derived exclusively from agricultural sources. Acetone was produced by the distillation of wood and later by the fermentation of various agricultural products. Butadiene, used for synthetic rubber, was made from ethyl alcohol before 1920. All of these chemicals are derived chiefly or entirely from petroleum and natural gas at the present time.

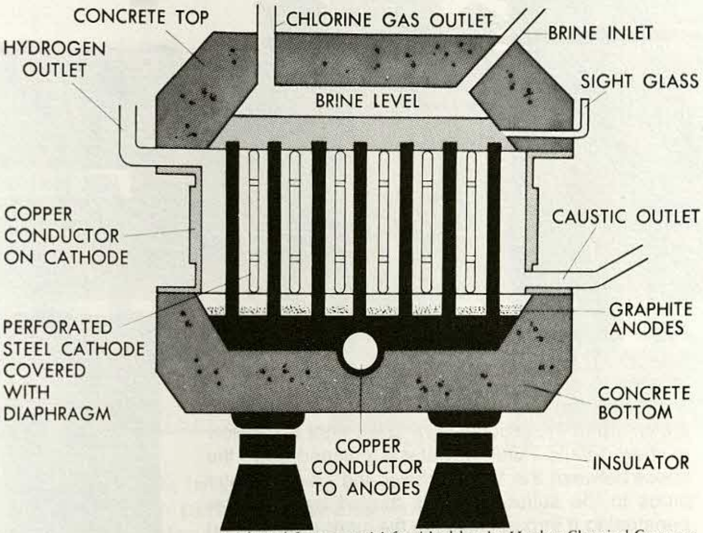
From the three fossil fuels mentioned above—coal, petroleum, and natural gas—the so-called *synthesis gases* can be derived. The processes involved in the manufacture of synthesis gas include partial oxidation by air, oxygen, or steam, with or without a catalyst, and sometimes at high pressure. These processes can be made to yield either ammonia synthesis gas, a mixture (not a compound) of hydrogen and nitrogen; or a methanol synthesis gas, a mixture (again, not a compound) of hydrogen and carbon monoxide.

When ammonia synthesis gas is compressed, slightly heated, and passed over a catalyst, it yields ammonia:

$$3H_2 + N_2 \rightarrow 2NH_3$$

3 molecules of hydrogen ($3H_2$) plus a molecule of nitrogen (N_2) yield 2 molecules of ammonia ($2NH_3$).

Methanol synthesis gas is made into



Adapted from material furnished by the Hooker Chemical Company

Hooker cell for producing chlorine (Cl_2) by electrolysis, or electrical decomposition, of brine—a water solution of sodium chloride (NaCl), or common salt. The chemical reactions caused by current passing from negative electrodes (cathodes) to positive electrodes (anodes) liberate chlorine from its union with the metal sodium (Na), and hydrogen (H_2) from the water (H_2O). Another important product of this process is sodium hydroxide (NaOH), better known as lye.

methanol, by a high-pressure catalytic reaction:

$$2H_2 + CO \rightarrow CH_3OH$$

2 molecules of hydrogen ($2H_2$) plus a molecule of carbon monoxide (CO) yield a molecule of methanol (CH_3OH).

Methanol is made into formaldehyde, which is a constituent of a large number of plastics.

CHLORINE DERIVATIVES

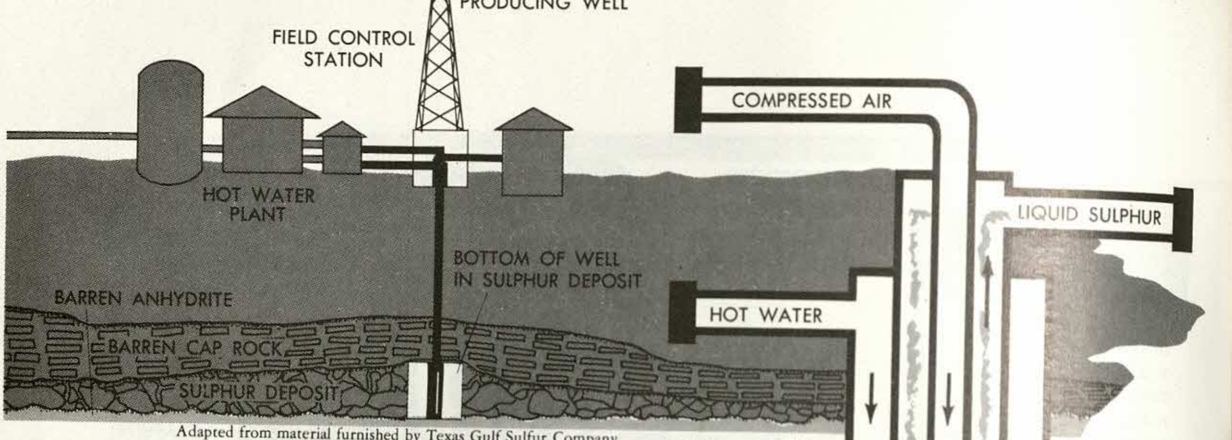
Chlorine (Cl_2) is a greenish-yellow gas, with an irritating odor. It has a suffocating effect when introduced in sufficient quantities into the respiratory system. It is a valuable source of different chemicals.

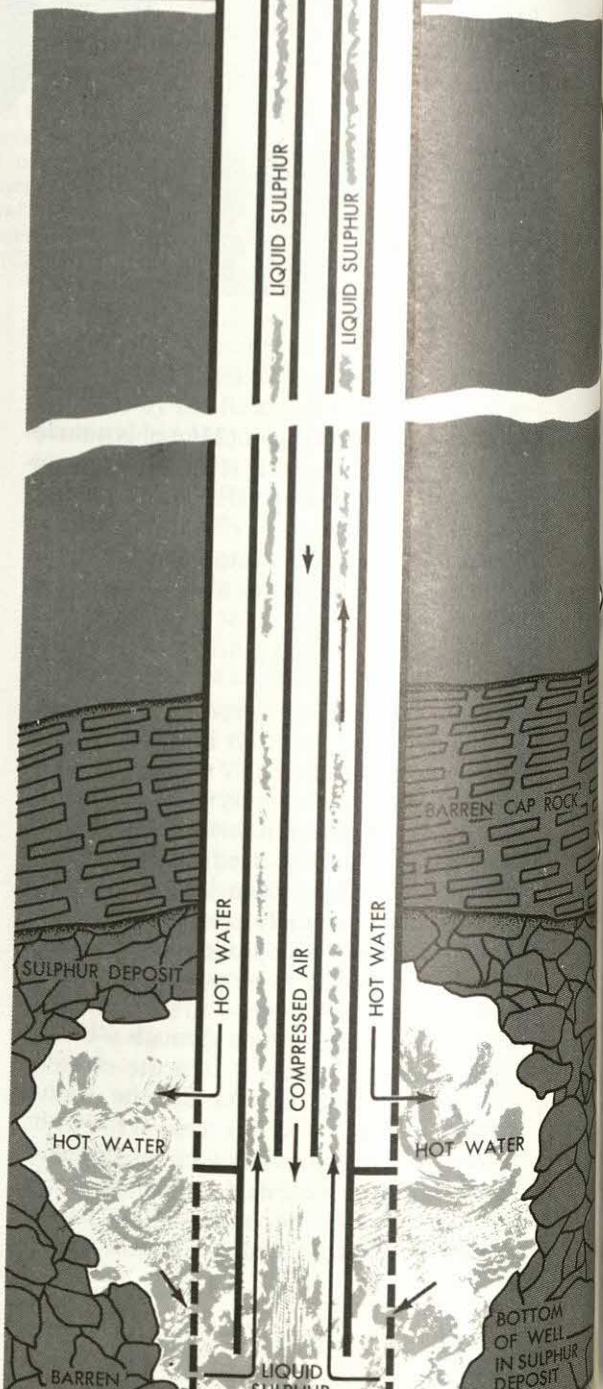
All the chlorine used in the chemical industry is derived from sodium chloride, NaCl, which is simply common table salt. Sodium chloride is decomposed by causing an electric current to be passed through it. This can be done in two ways. In one way, the electric current goes through a bath of molten salt and splits it into the elements chlorine and sodium. As for the sodium produced in this way, it is needed to synthesize certain dyes, and as a cooling medium for certain nuclear reactors. Sodium chloride can also be decomposed by passing electric current through a solution of sodium chloride in water. The main product is chlorine. The co-product is sodium hydroxide (NaOH), a large-tonnage chemical used in the manufacture of soap, textile manufacture, and petroleum refining. Sodium hydroxide underlies many other important operations in the chemical industry.

The chlorine derived by electrolysis from sodium chloride can be made to react with the hydrocarbons obtained from fossil

Hooker cells for the electrolysis of salt brine.

Hooker Chemical Corporation





Adapted from material furnished by Texas Gulf Sulfur Company

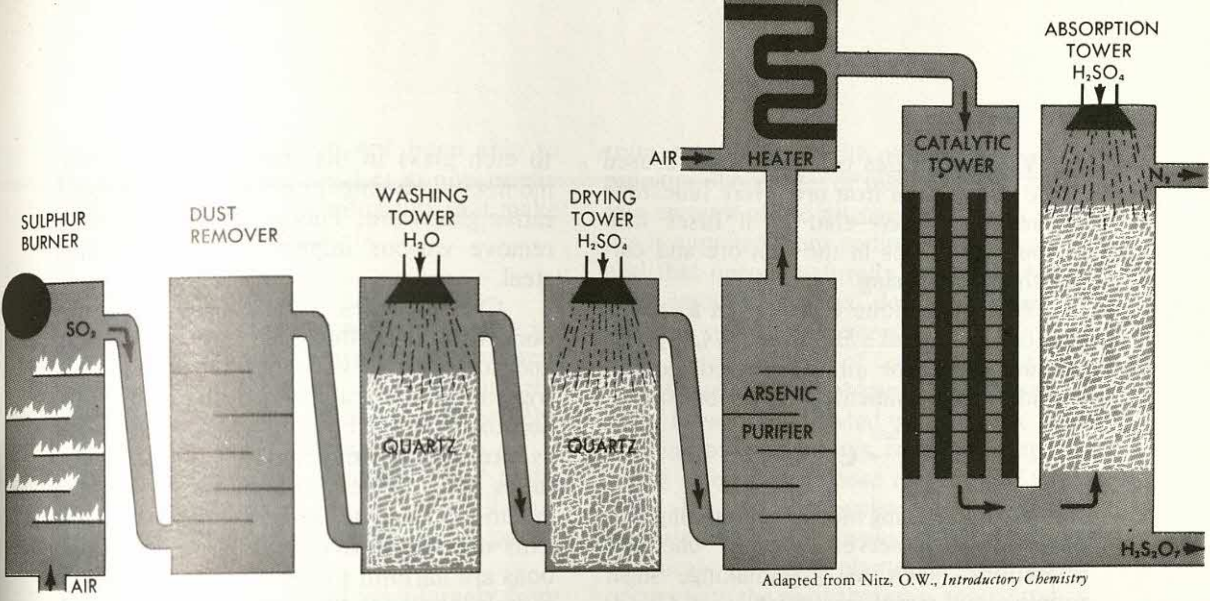
Frasch process for raising sulfur from underground deposits. Three concentric pipes, 15,7.5, and 2.5 centimeters in diameter respectively, lead down to the sulfur. The top and bottom parts of the pipe system are enlarged in sectional view at the right and below to show details. Pure hot water is pumped down the space between the 15-centimeter and 7.5-centimeter pipes to the sulfur, which is melted by hot water penetrating it through holes in the outer pipe. Melted sulfur sinks and then enters the 7.5-centimeter pipe. Compressed air from the central, 2.5-centimeter pipe aerates the sulfur, forming a froth that moves upward through the 7.5-centimeter pipe to the surface of the earth.

fuels. This results in the chemicals known as *chlorohydrocarbons*—a word that denotes compounds containing carbon, hydrogen, chlorine, and no other element. The chlorohydrocarbons are versatile materials. They are used in making more than one kind of synthetic rubber as well as the antiknock compound in gasoline. They also serve in the production of paint removers, refrigerants, vinyl plastics, several types of insecticides, and in electric insulation, as well as in dry cleaning and fireproofing.

SULFUR DERIVATIVES

Sulfur enters the chemical industry from several sources. Among the more important of these are sulfur-containing deposits in Sicily, Louisiana and Texas in the United States, and parts of Mexico. At one time, the sulfur deposits of Sicily were the chief source of the world's sulfur. They still account for considerable quantities.

Most of the world's sulfur is produced in the United States from the free deposits in Texas and Louisiana. It is not necessary to mine the sulfur. It is taken out by the method known as the *Frasch process*. A hollow iron casing is driven down into the sulfur-bearing deposits. Within this casing



Adapted from Nitz, O.W., *Introductory Chemistry*

Contact process for making sulfuric acid (H_2SO_4). At far left, sulfur is burned to produce the gas sulfur dioxide (SO_2), which is then passed through a series of chambers where dust is removed, it is washed in water, and then dried in sulfuric acid. The SO_2 is next purified in arsenic and led to the catalyst (usually a compound of vanadium), which causes SO_2 to combine with oxygen (O) to form sulfur trioxide (SO_3). SO_3 is absorbed in sulfuric acid to form $H_2S_2O_7$. Water is added to make sulfuric acid.

are three concentric pipes. Superheated water, at a temperature of about 165° Celsius, is forced down between the two outer pipes onto the ore bed. Since the melting point of sulfur is only 110°-120° Celsius, the hot water melts the sulfur. Compressed hot air is pumped down the innermost pipe. A mixture of hot water, hot air, and molten sulfur is then forced up to the surface in the form of a froth through the space between the innermost pipe and the one next to it. The sulfur obtained in this way contains almost no impurities.

Sulfur is also obtained as a by-product of some smelting processes. The ores of many valuable metals, such as copper and zinc, are sulfides – that is, compounds of sulfur and the desired metals. When these ores are *roasted,* freeing the metals, the sulfur is obtained in the form of sulfur dioxide, from which sulfuric acid is then derived. A certain amount of sulfur is also obtained from "sour" natural gas – the bad-smelling hydrogen sulfide, H_2S.

Most sulfur is converted into sulfuric acid (H_2SO_4), which is manufactured in greater quantities than any other chemical. The uses of sulfuric acid are legion. It serves in the manufacture of fertilizers. It is indispensable in *steel pickling* – removing the rust that covers manufactured steel at various stages of processing. It serves in petroleum refining and in the manufacture of rayon, detergents, dyes for textiles, and pigments for paint. It is used, too, as a reagent in the chemical laboratory.

Free sulfur also has many uses. It is a basic material in vulcanizing. It is an active material in many fungicides. It serves in various medicinal products, such as sulfur ointment, to combat various microorganisms. The compound sulfur dioxide (SO_2) is used in preserving fruits.

LIMESTONE DERIVATIVES

Limestone is made up mostly of calcium carbonate. It often contains various other compounds, such as magnesium carbonate and some compounds of iron and aluminum. There are vast limestone deposits in every continent. Most were laid down in areas that were formely covered by the sea. Many deposits were derived from the shells of sea creatures that lived millions of years ago, others from calcium carbonate that was contained in seawater and that was precipitated. Limy muds were formed in the course of the ages and solidified into limestone, which became available as the oceans receded and the land was raised.

Vast quantities of limestone are used in the smelting of iron ore. Here limestone is used as a *flux*—that is, it fuses with various impurities in the iron ore and carries them off as slag.

When limestone is heated in a special kind of kiln, called a *limestone kiln,* it yields calcium oxide, or *quicklime*, and carbon-dioxide gas, as indicated in the formula

$$CaCO_3 \xrightarrow{\text{heat}} CaO + CO_2$$

It is used in making mortar for building purposes. It also serves in many chemical operations, such as glassmaking, sugar refining, and water treatment.

In a very special use of lime, it is mixed with coke from coal (or petroleum) and heated to make calcium carbide, CaC_2. When water is added to calcium carbide, acetylene, C_2H_2, is obtained. This is used sometimes, though on a small scale, to make a very brilliant light. It is also used in welding and other operations requiring a hot flame. Actually, however, its most important use is as an intermediary compound in the manufacture of many chemicals.

FLUORINE DERIVATIVES

Fluorine is the most active, chemically, of all the nonmetallic elements. It is the most electronegative of all the elements. Hence it combines readily with almost all the chemical elements. In fact it has been made to react with xenon and krypton—so-called inert gases. Fluorine is a pale-yellow, highly poisonous gas. A number of its compounds are toxic.

Fluorine is found in nature as an element in various compounds. The most important source of the element is fluorspar, calcium fluoride, CaF_2, which has long been used in metallurgy to lower the melting points of various ores. Fluorine is also a constituent of the mineral cryolite (Na_3AlF_6), which is used in the processing of aluminum. Elementary fluorine is generally obtained by the electrolysis of hydrogen fluoride (HF).

Fluorine and its compounds have a variety of industrial uses. Hydrofluoric acid (HF) reacts with glass and therefore is used to etch glass in the manufacture of thermometers, chemical containers, and decorative glassware. This acid is also used to remove various impurities from stainless steel.

Certain gases, such as the fluorocarbons, containing fluorine, carbon, chlorine, and sometimes hydrogen, are ideal as refrigerants, particularly because they are nontoxic. These compounds are also used as propellants in aerosols, put in spray tubes to deliver insecticides, shaving creams, cake icing, and other preparations. This use is controversial, since fluorocarbons are harmful to the ozone layer, an atmospheric layer that protects the earth from the sun's rays. Their future use as propellants will be limited.

The name fluorocarbons denotes compounds consisting of carbon and fluorine atoms. They have found many uses: among other things, as insulation for electric wire and in the manufacture of plastic tubing. A fluorocarbon called PTFE (for polytetrafluorethylene) has become well known in the kitchen, because of the fact that water will not wet it. PTFE is better known by some of the trade names, such as Teflon, among others, given to it. It has remarkable nonstick properties. If a pan has been coated with the substance, you can fry eggs without any butter or fat, and they will not stick to the pan. PTFE is an example of an *abherent*—the opposite of an adherent. An *adherent,* or adhesive, makes things stick. An abherent prevents them from sticking. PTFE is remarkably smooth and slippery. For this reason it is sometimes used for bearings that never need lubricating.

Certain fluorides have been added to water in very small quantities in many communities, because fluorides markedly lessen the number of cavities that develop in the teeth. An excess of fluorides, such as sometimes occurs in certain natural waters, may have some bad effects. For one thing, they may cause teeth to become mottled.

THE CHEMICAL-PROCESS INDUSTRIES

We have turned the spotlight on some important raw materials of which the chemicals of industry are made. There are many others, which we have not been able to discuss for lack of space. Let us now briefly consider a few of the industries that make extensive use of chemicals.

FERTILIZERS

The fertilizer industry is now a huge industry in the United States. It will become increasingly important throughout the world as efforts are redoubled to feed the world's growing population.

Three principal elements have to be provided in suitable form in fertilizers. These are nitrogen, phosphorus, and potassium.

Nitrogen is supplied very largely from ammonia derived from fossil fuels. Ammonia for fertilizers is available in several forms. It may be used as ammonium nitrate, be combined with phosphates, as ammonium phosphate, or used as urea. A certain amount of the nitrogen used in fertilizers is supplied from sodium nitrate, a mineral that occurs naturally in Chile. A certain amount, too, is derived from ammonium sulfate, recovered as a by-product from the conversion of coal into coke.

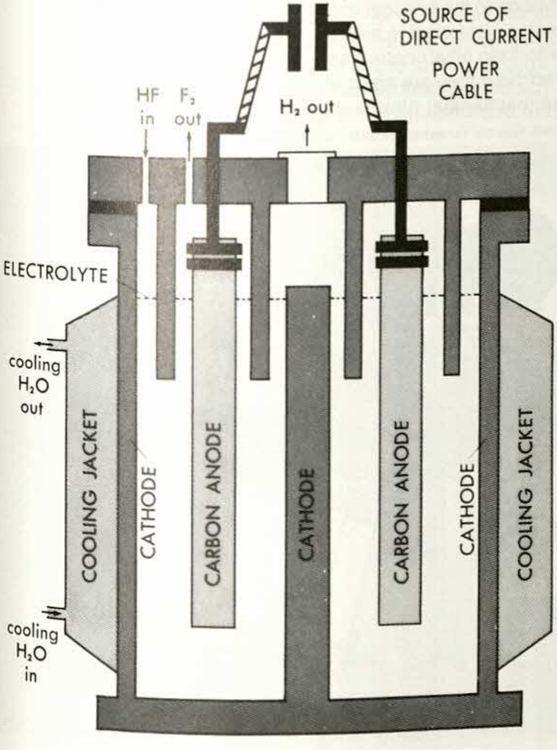


Diagram of cell for production of fluorine gas (F_2). Hydrofluoric acid (hydrogen fluoride, HF) is decomposed by electricity to yield free fluorine and also hydrogen gas (H_2). The interior sides of the steel cell and the central partition act as cathodes, or negative electrodes. The anodes (positive electrodes) are made of carbon. HF is mixed with a conducting solution, or electrolyte, so that current is able to pass.

Adapted from information furnished by Allied Chemical Corporation

Phosphorus is obtained as phosphate rock. It has to be treated with sulfuric acid, or in various other ways, to make it applicable as a fertilizer. These methods of treatment also lead to phosphorus products that are valuable in other ways, such as laundry chemicals. (In some plants, fluorine, which occurs with the phosphates, is recovered, in a form suitable for fluoridating water.) Phosphorus can be used in various forms as a fertilizer—as superphosphate, triple superphosphate, and phosphoric acid, which can be converted into ammonium phosphate.

Potassium, in the form of several of its salts, is obtained from mines. The principal sources are Germany, France, and the United States, in that order. Potassium compounds, nitrogen compounds, and phosphorus compounds are mixed together in most of the fertilizers used nowadays. In many cases there are added small quantities of trace elements that may be necessary in certain regions. These trace elements include zinc, molybdenum, copper, and boron.

EXPLOSIVES

Allied in some ways to the fertilizers are the explosives. These substances are not used by any means exclusively as ammunition. Various explosives are used in mining, quarrying, demolition work, prospecting for petroleum, and the excavation of oil and gas wells.

Many explosives—like many fertilizers—contain nitrates, or compounds obtained from nitric acid. Ammonium nitrate is important. It cannot be made to explode by itself but it is an ingredient of many explosives. Cellulose nitrate and glyceryl nitrate, or nitroglycerin, are important nitrogen-containing explosives.

Many modern explosives are in plastic

form. The old-fashioned gunpowder, a mixture of potassium nitrate with smaller amounts of charcoal and sulfur, is much less used now than formerly. It serves sometimes in ceremonial salutes and in fireworks.

DYES

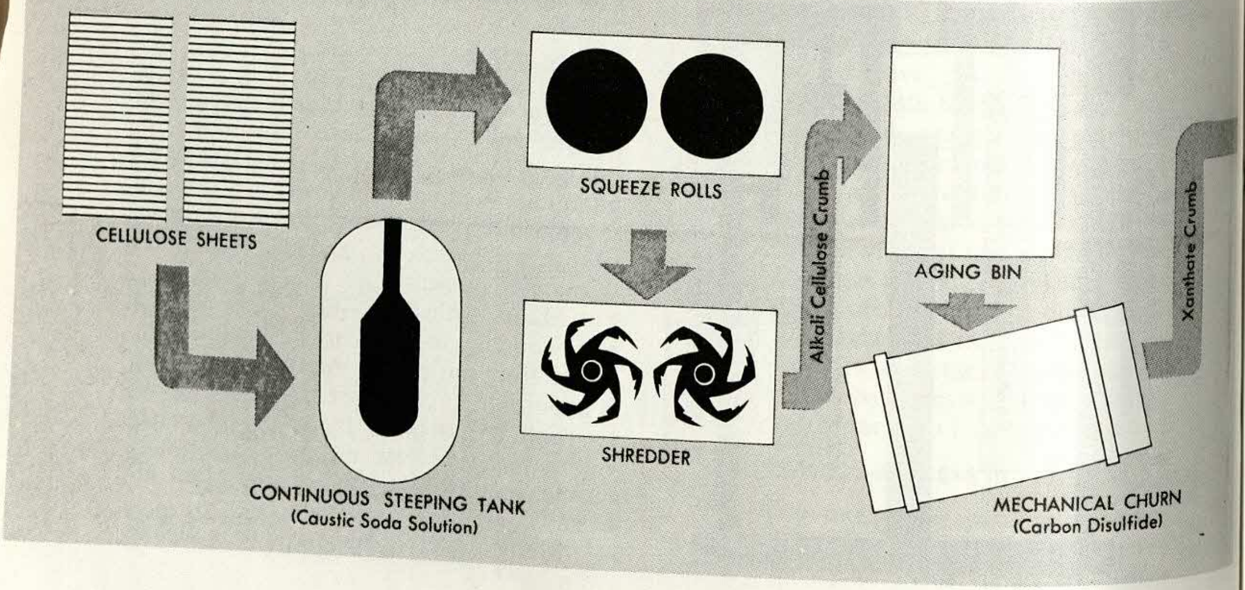
The chemistry of dyes is one of the classical triumphs of the organic chemist. Starting with the products of coal tar, he has synthesized thousands of dyestuffs, ranging through the colors of the rainbow. They have not only matched and duplicated nature's colors, but have surpassed them in uniformity, brilliance, and permanence. The ultimate consumer is constantly in contact with dyes produced through chemical means. The garments that you wear are practically all dyed. If you look around the room your eye will light on dyed products in the rugs that cover the floor, in the paint or wall paper on the wall, in curtains, lamp shades, plastic fixtures, books, book jackets, pictures, color photographs, and decorated objects.

DRUGS

In the early years of the twentieth century, the German researcher Paul Ehrlich was a pioneer in the investigation of new organic chemicals to find those with curative action against various diseases. In those days *chemotherapy*—the use of chemicals to heal disease—was something new. Today, the use of synthetic drugs, made from a bewildering variety of chemicals, has become universal. The sulfa drugs and the antibiotics have revolutionized the practice of medicine. The medicine that the doctor last prescribed for you was manufactured, in all probability, in a large establishment from a variety of organic chemicals. You can be sure, too, that in this establishment many researchers are engaged in a constant search to find new synthetic drugs to be used against diseases that have not yet been conquered.

Manufacture of viscose rayon involves chemical alteration of raw cellulose into a thick (viscous) liquid which can be forced into the shape of fibers. The fiber is then chemically converted back into a cellulose similar in composition to the original material. Cellulose from wood pulp or cotton, in the form of sheets, is steeped in a tank of caustic soda, which unites chemically with the cellulose to form alkali cellulose. The wet sheets are then squeezed through rolls and shredded. Next they are aged in a special bin. The alkali-cellulose crumbs are then put into mechanical churns, to

Adapted from material furnished by FMC Corporation, American Viscose Division



TEXTILES

There was a time when the only fibers used for making textile fabrics were derived from cotton, wool, silk, and linen. These fibers are all polymers—that is, they are made up of atoms of several different elements, arranged in a repeating pattern so as to form a very large molecule.

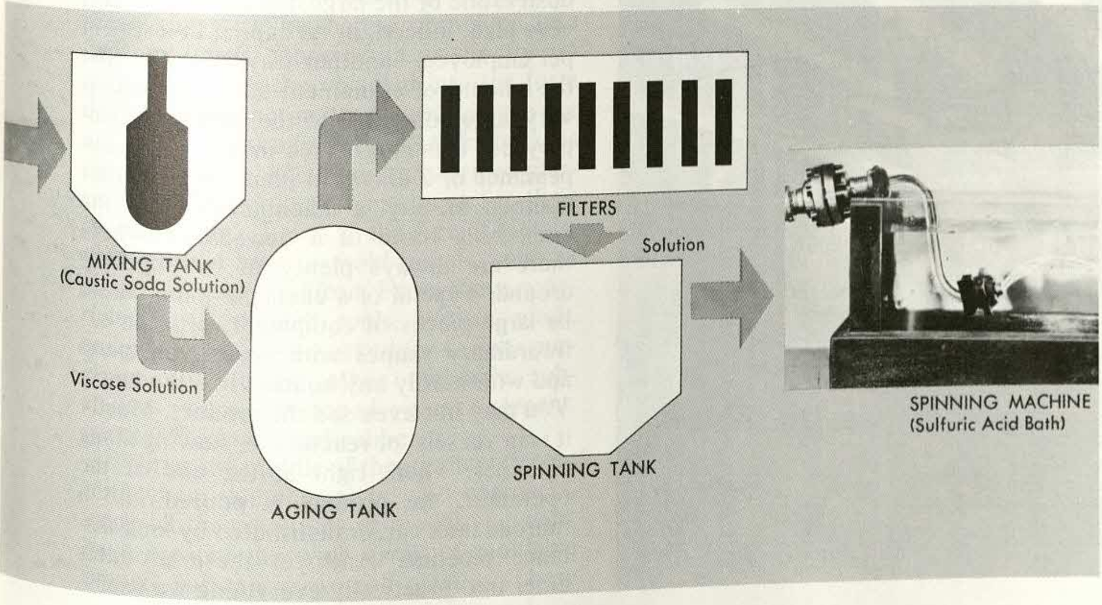
Chemists have now learned how to make entirely synthetic polymer fibers. The first was a modified natural polymer. Cellulose, either from cotton or from wood, was dissolved in a solvent, which could be either *xanthate* or a compound containing carbon and sulfur, or *cuprammonium,* which is made from a copper salt and ammonia. This solution was then squirted out through extremely fine holes into a bath of a chemical that would undo the chemical change brought about by the xanthate or cuprammonium. This would practically restore the original cellulose, only very slightly changed in its chemistry, but now in the form of continuous filaments. The resulting product was first called "artificial silk." This name was given up, however, because, although the product is very glossy, it is not really the same as silk. It is now called rayon. It is manufactured in extremely large quantities, for the textile industry. It is also used in tire cords.

Another way of treating cellulose is to dissolve it in acetic acid, ultimately producing cellulose acetate. It was originally called acetate rayon, but it is now simply known as acetate. It is decidedly different from regular rayon. For one thing, it needs a much lower ironing temperature.

Fibers such as rayon and acetate are called *semisynthetic,* since they start with a natural fiber. The first fully *synthetic fiber* to be successful was nylon, which belongs to the chemical family of the *polyamides.* Nylon was developed just around 1940. Nylon is used very widely in textiles and in tire cord. It has many other uses.

Polyester fibers (Dacron is the best

which carbon-disulfide compound is slowly added. This chemical reacts with the alkali cellulose to form cellulose-xanthate crumb, orange in color. The xanthate is now dissolved in caustic soda to form viscose solution, which is aged in a tank and then filtered to remove any dirt. The viscose is then of the right consistency and is fed into the spinning tank. There it is forced through the fine holes of the spinneret into an acid bath. The fibers thus formed are thereby converted into cellulose—the familiar rayon. The fibers are then collected and removed.



known brand name) and acrylic fibers (such as Orlon and Acrilan) followed, and they are in wide use. A newer fiber than these is Spandex, which is exceptionally useful in formfitting underwear.

PLASTICS

Also included among the synthetic polymers is the very large class of materials known as plastics. The first plastic—celluloid—was a modified form of cellulose. It was made by taking cellulose nitrate and making it more flexible by the addition of camphor. The most serious disadvantage of celluloid was that it was flammable. It was largely replaced in time by a variety of other plastics, including the formaldehyde group, the vinyl group, and newer cellulose derivatives that are not flammable.

They are used in innumerable applications: gadgets in the home; automobile parts; plastic garden hose; raincoats; instrument panels; electric plugs; buttons; game counters; and tableware. Methyl methacrylate and styrene plastics can be made in beautifully clear and transparent form. They can be used, say, for hairbrush handles and electric light fixtures, as well as for embedding decorative objects.

The textile industry is a chemical-process industry, dependent on chemicals to make fabrics crease-resistant and longer-wearing. Synthetics like polyesters and acrylics, and semisynthetics like rayon and acetate are chemically-processed.

Cotton, Inc.

SYNTHETIC RUBBER

Rubber is indispensable in modern life. It has innumerable uses in homes, industries, and hospitals, and in farms and play areas. It has been supplemented by synthetic rubber. Not all the rubber synthetics have all the qualities of the natural product, but each is equal or even superior to the natural product for certain purposes.

ELECTRICAL INDUSTRY

The electrical industry uses many chemical products. Sulfuric acid, diluted with water, serves as the electrolyte in lead-acid storage batteries. The surface coatings of electric motors are made of resinous materials—a product of the plastics industry. Synthetic rubbers, including silicone, butyl, and nitrile rubbers, are used for wire and cable insulation and couplings. High-temperature insulation is provided by the oxides and carbides of many metals.

In this short article, you have been given a brief glimpse of the chemical industry, one of the largest in the world. It is very high, indeed, in its capital investment per employee—another way of saying that the amount of equipment and apparatus is very large compared to the number of employees. This is reflected in the typical appearance of a chemical plant. It is in utter contrast to, say, a machine shop, or the composing room of a newspaper, where there are always plenty of busy people around. Typical of a chemical plant would be large pieces of equipment, often in extraordinary shapes with no moving parts and with hardly any humans in attendance. You may not even see the product. Mostly it is in vessels, or reactors, or flowing along pipelines. Then, right at the end of the operation, the product is poured into a railroad tank car, or distributed by long-distance pipeline. And yet these products enter into practically everything we use.

G. Walker/Liaison

Modern plastic fibers are found everywhere—on earth and above it.

PLASTICS

by Maurice W. Schwarz

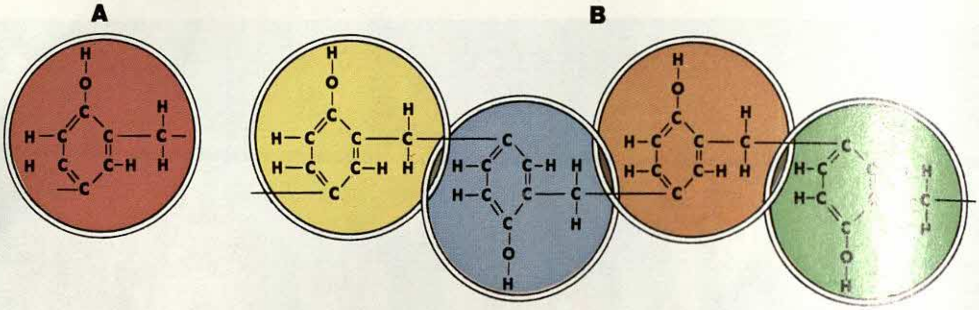
Plastics are found almost everywhere in the modern world. The reason why these materials are so useful is given in their name. To say that a material is "plastic" means that it can be shaped, or molded, into different forms. Stone is not plastic, for example. It has to be chiseled into the form desired. But other materials that people use are plastic to some extent. As far back as the New Stone Age, men transformed plastic clay into pottery containers for their food and drink. Later, in the Age of Metals, they learned how to mold metals, such as copper, bronze, and iron. From these materials they fashioned tools. Waxes, pitch, and gums were also worked for various purposes. Eventually, other moldable substances were developed—glass, cement, concrete, plaster, and rubber.

Since the middle of the nineteenth century, chemists, physicists, and engineers, using all the resources of modern science, have created the wide array of moldable organic substances we call plastics. These versatile materials are used in the manufacture of many products, from golf tees to lifeboats; from movie film to wall panels; from hosiery thread to towing rope; from overshoes to raincoats; from drinking straws to water pipe; from table tops to wrappings for meat and vegetables.

All plastics are moldable, but not all moldable substances are called plastics. Inorganic substances that can be molded, such as metals, clay, glass, and concrete, are not considered to be within the scope of the plastics industry. Neither is rubber.

MADE OF POLYMERS

Each one of the plastics consists of, or contains as a basic ingredient, an organic substance with high molecular weight that can be softened and molded under applied heat or pressure, or both. It is made up of giant molecules called *polymers*. Each polymer consists of smaller molecules joined end to end like a chain. Sometimes the chains are crosslinked, in chain-armor



The synthetic resin phenol-formaldehyde is a long-chain polymer based on the unit, or "link," illustrated in *A* above. In *B*, we show a few links in the polymer chain. The letters C, O and H stand for the carbon atom, oxygen atom, and hydrogen atom, respectively. The straight lines between atoms represent bonds. It is to be noted that each carbon atom has four bonds, each oxygen atom two bonds, and each hydrogen atom one bond.

fashion. In some cases, each link in a given chain is the same basic unit, or *monomer*. Some polymers, known as *copolymers*, are made up of a mixture of two or more monomers.

Most plastics are produced by the synthesis, or building up, of various chemicals, yielding a product in which carbon is combined with one or more other elements, including hydrogen, oxygen, nitrogen, chlorine, and fluorine. The term *synthetic resin* is often applied to such plastics because in some respects they resemble the natural substances called *resins*. These include shellac, rosin, and amber and are noteworthy for the large size of their molecules. In preparing the synthetic resins, it is necessary to build up smaller molecules into polymers under carefully controlled conditions. Examples of synthetic resins are the *alkyds, phenolic resins*, and *vinyls*.

Other plastics are derived from natural organic substances, which are modified chemically to produce the desired plastic material. The *cellulosics*, for example, are derived from *cellulose*, a carbohydrate found in plants and readily obtainable from cotton and wood pulp.

Casein plastics are produced from the protein *casein*, which is formed when milk is curdled. The basic molecules of such natural organic substances are polymers. It may be necessary to reduce the size of these giant molecules in order to produce a material that is easy to mold on an industrial scale.

TWO MAJOR GROUPS

All plastics can be divided into two major groups, which are called *thermoplastic* and *thermosetting* and which differ in the way in which they are affected by heat. Thermoplastic materials become soft when they are heated and they harden when they are cooled. If heat is applied again, they become soft once more. They can be molded in the same shape or in a different shape. Only a physical change is involved and not a chemical change. Various substances that are not plastic also act in this way. Paraffin wax is a well-known example. Among the thermoplastics are *cellulose acetate* and *polystyrene*.

Thermosetting plastics are affected quite differently when heat is applied to them. They first become soft and then hard, and after that they cannot be softened again by the application of heat. The permanent hardening, called *curing*, is a chemical change. It may be compared to the hardening of an egg in boiling water. The thermosetting plastics, or *thermosets*, as they are sometimes called, include the *phenolics* and the *epoxies*.

PIONEERS IN PLASTICS

The first commercial plastic was Celluloid, a *cellulose nitrate*, which was created by John Wesley Hyatt, a U.S. printer, in 1868. He had entered the competition for a $10,000 prize, offered for the best substitute for ivory in the manufacture of billiard balls. Hyatt decided to try pyroxylin, a cellulose nitrate, as an ivory substitute. The British chemist Alexander Parkes had reported that if tyroxylin, which is brittle and cannot be molded, was mixed with camphor, the resulting substance was moldable.

It did not stand up well, however, under hard use. Hyatt improved upon the mixing process, using pressure and heat, and he produced a plastic material that he called Celluloid. It could be formed, machined, and rolled. It was not quite right for billiard balls, unfortunately, and Hyatt did not win the competition.

However, he found that Celluloid was a fine substitute for ivory in many products. In the early days, it was used for denture plates, collars, cuffs, and shirt fronts. Later, it served for photographic film, automobile window curtains, hairbrush handles, and many other products. Its position was unchallenged for years, but it lost ground rapidly after better plastic materials were developed in the present century.

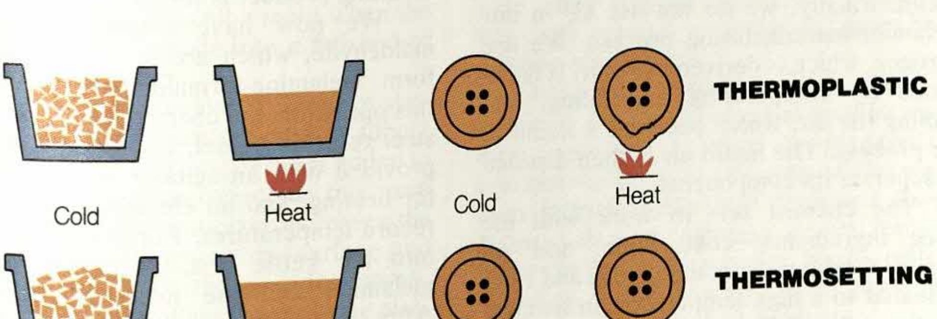
In the last years of the nineteenth century, two German chemists, Wilhelm Krische and Adolph Spitteler, began looking for a composition material to replace slate for blackboards. They discovered that the action of formaldehyde on casein produced a hornlike substance—a plastic that lent itself to many uses. About 1900, the commercial production of casein plastic was begun in Germany and France. The product received the trade name of Galalith ("milk stone"; from the Greek *gala:* "milk" and *lithos:* "stone").

Another important name in the history of the plastics industry is that of Dr. Leo Baekeland, a Belgian-American chemist. The eminent German chemist Adolf von Baeyer had noted in 1872 that resinous masses were formed when various phenols and aldehydes reacted together. These resinous materials were not used in industry until 1909. In that year, Baekeland discovered how to control the reaction between phenol and formaldehyde so as to produce a useful phenolic plastic product, which was given the trade name of Bakelite. It could be formed by casting, or by molding under heat and pressure. In solution, it could be used as adhesive to bond together layers of wood, cloth, paper, and other materials. Bakelite was the first commercial synthetic resin.

Since 1909, a great many other kinds of plastics have been developed and produced commercially. The plastics industry has been growing steadily and has invaded one field after the other. In the United States alone, millions of kilograms of plastic materials are produced for many purposes every year.

A TYPICAL PREPARATION PROCESS

Generally speaking, the chemicals from which plastics are made do not occur as natural products. They must be manufactured from available resources, such as petroleum, natural gas, coal, limestone, salt, fluorspar, sulfur, water, and air, to name some of the more important. The fact that we have to go back to such basic materials in the manufacture of plastics has led to statements such as "Nylon is made from coal, air, and water" and "Polyvinyl chloride is made from coal, limestone, salt, and water." This is certainly an extreme form of simplification. It suggests a magician's



Dupont

Thousands of everyday objects are made of versatile plastics.

sleight of hand in breaking some eggs into a top hat and turning out an omelet. Actually, it is a complicated task to transform basic natural materials into chemicals and to change the chemicals into plastics. Elaborate equipment must be provided. Skilled scientists, engineers, and technicians must be employed.

To give some idea of just what is involved, let us outline the processes used in the manufacture of the synthetic resin melamine-formaldehyde, which is a combination of melamine and formaldehyde.

The starting materials for the manufacture of melamine are coal, limestone, and air. We do not use coal itself as an ingredient. Rather we use coke, which is derived from coal. It is obtained as a by-product together with coal gas and coal tar, when bituminous coal is heated in an oven. Similarly, it is not limestone that we use as an ingredient in the manufacture of melamine. It is lime, which is obtained, together with carbon dioxide, when limestone is heated in a kiln. Finally, we do not use air in our melamine-manufacturing process. We use nitrogen, which is derived from air. It is obtained by compressing, expanding, and cooling the air, which becomes a liquid in the process. The liquid air is then distilled to separate its components.

The chemist sets to work with the three ingredients—coke, lime, and nitrogen. A mixture containing lime and coke is heated to a high temperature in an electric furnace and forms calcium carbide and carbon monoxide. The calcium carbide is heated with nitrogen in an electric oven, and the product is calcium cyanamide. This chemical reacts with water and acid to form cyanamide, from which dicyandiamide is obtained by treatment with alkalies. Finally, dicyandiamide is heated with ammonia and methanol to produce melamine. So now we have the melamine component of the melamine-formaldehyde resin.

The starting materials for the manufacture of formaldehyde are coal, water, and air. First of all, the coal must be converted to coke, by the process we just described. The coke is then made to react with steam to form hydrogen and carbon monoxide. When these two gases are heated under high pressure in the presence of chromic oxide and zinc oxide or some other catalyst, methanol is formed. Methanol vapor is then made to combine with the oxygen contained in air, with the aid of a catalyst. The resulting product is formaldehyde.

We now have melamine and formaldehyde, which are to be combined to form melamine-formaldehyde resin. For this operation, the chemist uses a stainless-steel reaction vessel, called a *kettle*. It is provided with an agitator, a steam jacket for heating, and an electric instrument to record temperatures. Formaldehyde is run into the kettle first. It is followed by melamine and the necessary catalysts. After the mixture has been heated and stirred by the agitator for a sufficient time, the liquid resin is drawn off and pumped through a filter press to remove solid impurities.

The filtered liquid resin is then mixed in a stainless-steel double-arm mixer with sulfite pulp, which has been derived from wood by chemical and mechanical treatment. The mixed resin and sulfite pulp are dried. They are then broken down by a cutter and mixed with various modifiers, or added substances, by grinding in a *ball mill*. These modifiers include *colorants* or coloring agents, lubricants, and catalysts. Some of the ground mixture is screened to remove fine particles. It is then packed in drums and sold as *plastic molding powder*. The rest of the mixture is compacted (pressed together) and is passed through a cutter to produce grains of the required size. After screening, it is packed in drums and is sold as a material called *granular molding compound*.

This, then, is a very brief outline of the many chemical and physical processes required to transform coal, limestone, air, and water into a typical plastic material—melamine-formaldehyde.

MODIFIERS

Many other processes are employed in the manufacture of plastics. The addition of modifiers is of great importance in practically all cases, since synthetic resins by themselves are usually not suitable for molding purposes.

Colorants are almost always added. They include dyes and pigments, such as red cadmium, yellow cadmium, and white titanium-dioxide pigments.

Lubricants are also generally included. They make it easier to fill a mold when the molding powder is made into a finished or semifinished product.

Some plastics develop a charge of static electricity, which causes dust to adhere to their surfaces. *Destaticizers* are added to the plastic mixture to overcome this trouble. One type of destaticizer increases the electrical conductivity on the surface and thus allows the static charge to leak away.

Exposure to sunlight causes some plastics to deteriorate. This is offset by the addition of substances called *stabilizers*, which include organic-acid compounds of barium, cadmium, calcium, and zinc.

Presse-Sports

Strong, flexible fiberglass is widely used in the manufacture of sports equipment

Other modifiers serve as *flame* and *fire retardants*. Among these are organic phosphorus compounds, which are chemically combined with bromine or chlorine.

When suitable fillers, such as carbon black, clay, cotton flock, mica, and wood flour, are mixed with plastics, they add bulk, make the material less porous, and reduce the over-all cost. *Plasticizers* are other important modifiers. They are in liquid or solid form and they are added to plastic powder to improve flexibility and provide other desired properties. Something like 400 organic compounds have been used as plasticizers.

After modifiers have been added as required, the plastic material may be made into a powder or may be prepared in granular form, as in the case of the melamine-formaldehyde resin described above. It may also be supplied in the form of pellets or flakes. As powder, grains, pellets, or flakes, it is now ready to be made into finished or semifinished products.

Plastics are used in piping for drainage and waste systems, providing greater flexibility for the installer and lower costs for the consumer.

Dupont

IMPORTANT GROUPS

There are thousands of plastic materials today and they are marketed under a profusion of trade names. For example, Herculoid, Nitron, and Rowland CN are all trade names for cellulose nitrate. Beetle, Plaskon, and Catalin are trade names for urea-formaldehyde. Styron, Lustrex, and Bakelite Polystyrene are trade names for polystyrene. It would obviously be impossible in this short article to name each of the available plastic materials, to say nothing of the even more numerous trade names by which they are known. In the paragraphs that follow, we shall give a list of the more important plastic groups, with a brief account of the characteristics and principal uses of each group.

Acrylic resins. These are thermoplastic materials that are noted for their toughness, weather-resisting qualities, and clarity. Polymethylmethacrylate is the most important resin in this group. It is best known under the trade names Plexiglas and Lucite. It remains clear after weathering, resists impact, is available in a wide range of colors, burns slowly, and does not become brittle when cold. It serves for display signs, automobile taillights, hairbrush backs, combs, and costume jewelry. It is well suited for glasslike materials used in airplanes because of its clarity and its resistance to weather.

Alkyd resins are thermosetting. They are fine electric insulators and resist heat. They are widely used in paints, enamels, lacquers, adhesives, and printing inks. Alkyd molding materials serve in light switches, fuses, automobile starters, and electron-tube bases.

Allylic resins, which are thermosetting plastics, are excellent electric insulators and have low water absorption and low shrinkage during and after the molding process. They are molded to form automotive ignition parts, coil forms, distributor caps, commutator assemblies, electron-tube bases, and other electric and electronic parts. The allylic resin called diallyl phthalate provides reliable electric insulation under the most adverse conditions of temperature and humidity. For this reason, it was used in the terminal equipment of the world's first transoceanic telephone cable system.

Amino resins are a group of thermosetting plastics which include melamine-formaldehyde resin and urea-formaldehyde resin. Molded amino products are translucent or opaque. They are glossy, have good colorability, and are free of odor or taste.

Melamine-formaldehyde resin has low moisture absorption and gives a smooth hard surface. Hence it is used in great quantities for tableware, buttons, cases for hearing aids, and distributor heads. Urea-formaldehyde resin serves for radio cabinets and electrical devices, among other things.

Casein plastics are produced by the action of formaldehyde upon the protein casein, resulting in a tough, hornlike thermosetting material. Casein plastics have a brilliant surface polish and come in a wide range of colors. They are used for buttons, beads, game counters, pushbuttons, knitting needles, and toys.

Cellulosics, derived from cellulose, form a group that includes cellulose acetate and cellulose acetate butyrate. These materials are thermoplastic. They are tough and are available in a wide range of colors. Cellulose acetate is the most widely used of the cellulosics. It serves for fibers (acetate rayon), photographic film, buttons, combs, eyeglass frames, lamp shades, vacuum-cleaner parts, and floor polishers. Chessmen molded of this material are pleasant to the touch and sturdy. Finger marks upon them may be easily wiped off.

Cellulose acetate butyrate is superior to cellulose acetate in toughness and in low moisture absorption. It withstands weathering and is easily cleaned. It is an ideal material for automobile steering wheels, portable radio cases, tool handles, and telephone handsets.

Epoxy resins are chemically resistant thermosetting plastics. They are durable, flexible, and tough. They make fine protective coatings. They serve in primers, topcoats, and varnishes and as lining materials for cans, drums, pipe, tanks, and tank cars. Epoxy resins are outstanding as adhesives. They have also been employed increasingly for molding, casting, and laminating. Laminates, or combined layers, of epoxy resins and glass-fiber products have found wide application in printed electric circuits, aircraft, ducts, housings, tanks, and tooling.

Fluorocarbons excel in durability. They resist chemicals, flame, heat, and weathering. These thermoplastics are flexible at low termperatures and are good electrical insulators. They are employed for valve seats, pump diaphragms, gaskets, nonlubricated bearings, electronic parts, wire coatings, and tubing.

Phenolic resins are thermosetting plastics that possess strength, rigidity, and heat resistance. They have a natural brown color and are usually not provided in the bright array of hues that the public has come to associate with plastics generally. Phenolics are used for the items or parts where special mechanical or electrical properties are required, rather than colorability. Among other things, they serve for camera cases, distributor caps, electric-iron handles, switches, telephones, electron-tube bases, and washing-machine agitators. In liquid form, they are used as protective coatings and adhesives and in the manufacture of laminates.

Polyamide resins Nylon is the best-known of these resins. It is not a single plastic but a group of plastics, each with its own physical characteristics and uses. The word nylon suggests fabrics, stockings, or bristles to the general public, but these are but a few of the many uses of the nylons. Because nylon products are tough and resist abrasion, heat, and chemicals, they are molded to make gears, bearings, cams for speedometers, business-machine parts, and household appliances. They also serve for rifle stocks, rotary switches, silverware handles, and slide fasteners.

Polycarbonate resin is resistant to chemicals, heat, impact, and weather. This thermoplastic is used to make various parts for aircraft, automobiles, and business machines, and it has many applications in electrical and electronic devices. Like aluminum, brass, and copper, but

These temporary roofs are made of a fiberglass fabric coated with resin.

Chem Labs

Toys, floats, and masks may be made of plastics, which are easily molded into a variety of shapes.

Peter Karas

unlike most other plastics, it can be cold-forged (formed without the application of heat) by rolling, punching, and drawing to make disks, caps, and tubing.

Polyester resin compounds are thermosetting. They are excellent electrical insulators, have low moisture absorption, and resist heat. They are widely used for coatings. The fiber-forming polyester known under the trade name Dacron has become important in the textile industry. When reinforced with fibrous glass, asbestos, synthetic fibers, and other materials, polyester resins can be molded into various products which have outstanding electrical properties, are lightweight and strong, and can withstand impact. These reinforced materials are used for building panels, electrical-equipment parts, and many other products.

Polyethylene is among the most widely used plastics. This thermoplastic material is tough and can be made either rigid or flexible. It resists heat and cold, water, and weathering and is an excellent electrical insulator. Its many applications include pipe and tubing, jacketing for electric cables, flexible ice-cube trays, rigid and squeezable bottles, tumblers, dishes, mixing bowls, brush handles, and toys. In film and sheet form, it serves for bags for candy and food products, rainwear, balloons for meteorological observations, freezer bags, and moisture barriers under concrete and in walls. High-density polyethylene is rigid, resistant to water, weathering, food acids, and abrasion and is easy to clean. Hence it is an outstanding material for garbage cans.

Polypropylene, a thermoplastic, combines many valuable properties. It is lightweight, tough, strong, resistant to chemicals, boiling water, and cracking, and is a good electrical insulator. It is employed in dishes, pipe and tubing, valves, bottles, battery boxes, refrigerator parts, household articles, textile-machinery parts, and insulation for wire and cable. Polypropylene laboratory ware is impact-resistant, withstands temperatures up to 140° Celsius, and resists chemicals and cracking.

Polystyrenes are thermoplastics which are noted for their clarity, hardness, gloss, and electrical properties and are available in a wide range of colors. Their applications include kitchenware, food containers for refrigerators, instrument panels, wall tile, portable-radio housings, storage boxes, handles, and toys. Polystyrene rigid foams are supplied in plank, block, or sheet form and also as beads which can be processed into foams. They are used for packaging and as sandwich panels in buildings.

Silicones resist chemicals, heat, water, and weather and are fine electrical insulators. These thermosetting plastics are employed in aircraft and missiles, coil forms, connector plugs, generator insulation, switch parts, and terminal boards.

Urethane resins are thermoplastic materials. They form flexible, semirigid, and rigid foams, which are tough and lightweight and resist moisture. Flexible urethane foams have proved useful in automobile and airplane seats, bedding, crash pads, furniture cushioning, interlining for clothing, protective packaging, and thermal insulation for tanks. Rigid foam is serviceable as a core material for curtain-wall panels, low-temperature insulation, and packaging. Urethane resins are also used in adhesives, bristles, coatings, and solid plastic products.

Vinyl resins, or vinyls, are strong and tough thermoplastics which are good electrical insulators, resist chemicals, and are available in many colors. They are used for floor tile, handbags, phonograph records, raincoats, shower curtains, upholstery, garden hose, electric plugs, and wire and cable insulation.

There has, however, been increasing concern over the manufacture and use of vinyl plastics. Vinyl chloride, a chemical used in the manufacturing process, has been linked with a rare form of liver cancer. In 1974 and 1975 health rules were established, limiting manufacturing conditions and the use of some vinyl plastic products.

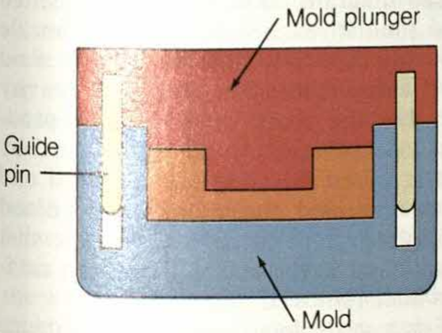
PROCESSING

If a manufacturer is thinking of using plastics for the products he makes, he wants to be sure that one or more of these materials will serve his purpose better than wood, metal, or ceramics. He will have to consider what the products are intended to do, how long they should stand up under wear, what properties they must have, and how many will be sold. He must also estimate at what price to sell the merchandise.

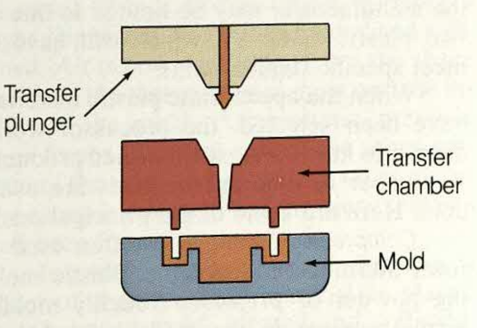
If the manufacturer finally decides upon the use of plastics, he or she will have to decide which plastic or plastics to select. Certain desirable properties are found in many different kinds of plastics: their resistance to rusting and tarnishing, their retention of their original color, and their smoothness. Other properties are characteristic only of a few plastic materials.

A manufacturer who produces brush and mirror backs, costume jewelry, kitchen items, tableware, and toys has a wide choice of plastic materials at his disposal. The situation is quite different, however, if the manufacture of electrical commutators, electronic parts, gears, pipe fittings, or washing-machine agitators. In those cases,

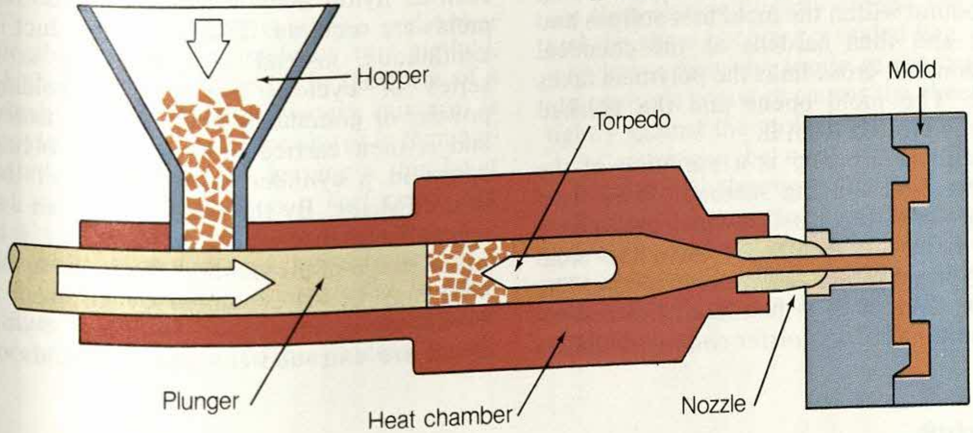
COMPRESSION MOLDING

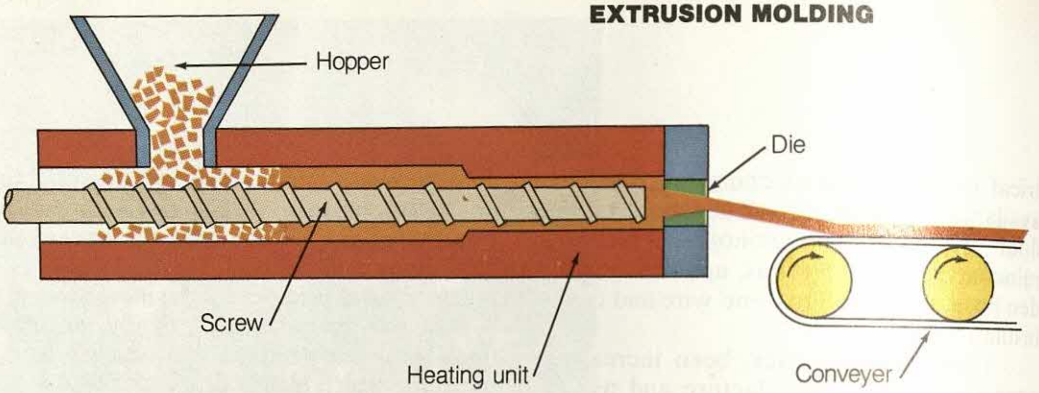


TRANSFER MOLDING

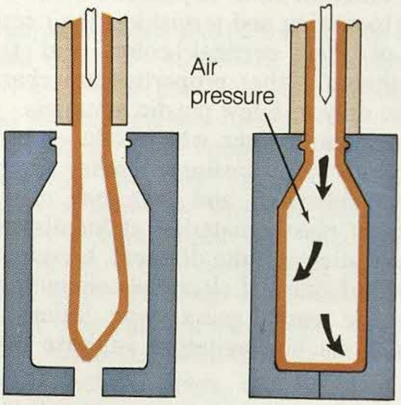


INJECTION MOLDING





EXTRUSION MOLDING



BLOW MOLDING

the manufacturer may be limited to one or two plastic materials, which will have to meet specific requirements.

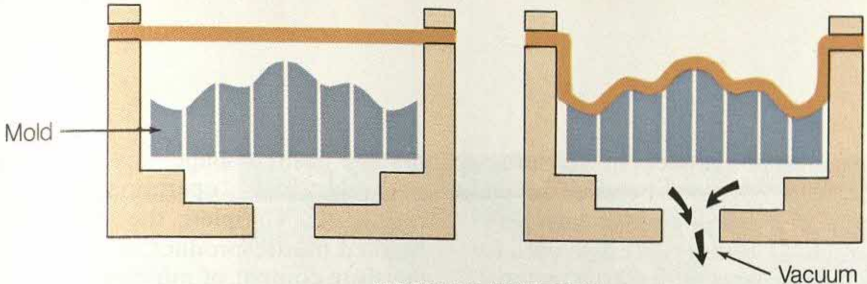
When the appropriate plastic materials have been selected, the processor works them into finished or semifinished products. A number of different methods are available. Here are some of the principal ones.

Compression molding is often used to form thermosetting plastics. Plastic molding powder or *preforms* (roughly molded forms) are set in the cavity of a heated mold. The mold is then closed by a plunger worked by hydraulic pressure. The molding compound within the mold first softens and flows and then hardens as the chemical reaction that cross-links the polymers takes place. The mold opens and the finished piece is ejected from it.

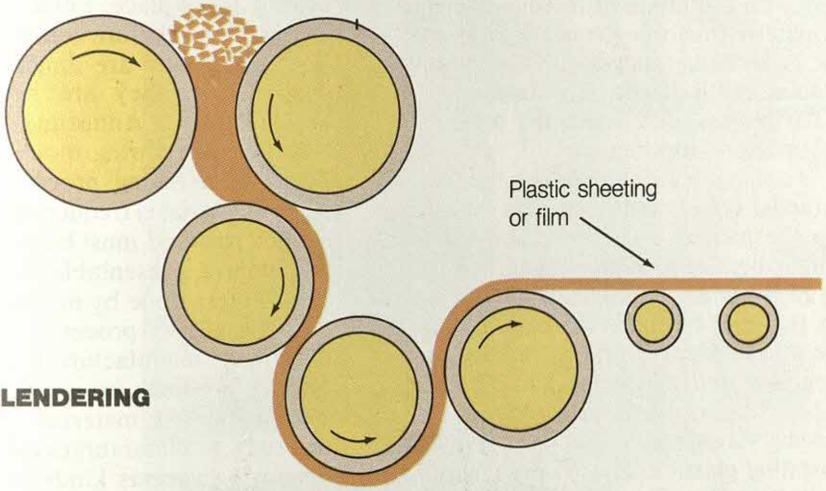
Transfer molding is a variation of the compression-molding method. It is used for thermosetting plastics which are to have deep holes for inserts or when the mold cavity has a rather complicated shape. The plastic compound is first heated in a separate pot, called a *transfer chamber*. Then a plunger forces the softened plastic from the transfer chamber into the cavity of the mold.

Injection molding is used to process various thermoplastic materials and is particularly effective in the rapid production of more or less intricate pieces. Often the mold consists of a number of small cavities, connected by channels, called *runners*. Each cavity serves as the mold for a single small item—a button, say. Molding pellets flow from a hopper into the rear end of a heating cylinder where heating starts. A plunger pushes the plastic forward and it is forced into the space between the walls of the cylinder and a heated *torpedo* in the middle of the cylinder (see diagram). The material is melted by the time it reaches the cylinder nozzle and is injected into the mold. The fluid plastic completely fills the mold cavity (which has the shape of the desired product) or the cavities that are connected by runners. When the plastic has cooled and has become solid, the mold is opened and the finished piece is ejected. Plastic that has solidified in the runners between cavities is later removed.

Extrusion molding serves to produce sheets, rods, tubing, pipe, and filaments, such as nylon fibers used in textiles. No molds are required. The flow of product is continuous, instead of proceeding in a series of cycles. The plastic molding powder or granular material is first heated and is then carried along by a revolving screw in a cylinder to an orifice of the desired shape. By the time it has been extruded, or pushed out, from the orifice, it is in the shape of a rod, sheet, or pipe, as the case may be. It is cooled by air from a blower or by immersion in water. Nylon fibers are extruded through thousands of



VACUUM MOLDING



CALENDERING

tiny holes in a die, called a *spinneret*.

Blow molding is used for the production of hollow thermoplastic containers, housewares, and toys. In one type of blow-molding machine, plastic material in the form of a tube is received from an extruder and is fed into the cavity of the mold. One end of the tube is then sealed off and after the mold has been closed, compressed air is blown through the other end of the tube. This causes the plastic to expand against the walls of the mold. It is cooled and hardened and then removed from the mold. Flexible polyethylene squeeze bottles are produced by blow molding.

Slush molding. Overshoes and other flexible objects are made by this method. A thermoplastic material in the form of a slush or slurry (a thin, watery mixture) is put in a warm mold. The slurry is then agitated and drained off, leaving a thin layer of material on the inner surface of the mold. This layer is fully fused by additional heat, cooled, and then stripped off.

Vacuum molding is also used to form finished plastic products. Atmospheric pressure plays a part in this process. In one method, a sheet of thermoplastic material is clamped over a hollow mold, forming a tight diaphragm, and is then heated and softened. Air is now withdrawn from the space between the thermoplastic sheet and the inside of the mold. Atmospheric pressure then forces the sheet against the inner surface of the mold. After cooling takes place, the clamp is released, and the piece that has just been formed is removed.

In another type of vacuum forming, a sheet of thermoplastic material is placed over a raised mold. Heated and softened, the sheet drapes itself over the projecting parts of the mold. The edges of the sheet are then clamped tightly around the mold, and the sheet becomes a sealed bag. Air is withdrawn from the inside of the bag, and atmospheric pressure causes the sheet to fit tightly against the mold.

Casting can be used with both thermoplastic and thermoset plastics. Acrylic and vinyl thermoplastics and phenolic, polyester, and silicone thermosets can be cast into shapes, film, sheeting, rods, and tubes. Pressure is not necessary in this method.

Calendering is a process in which thermoplastic material is fed between several heated *calenders*, or rollers, and emerges as a sheet or film. Calenders are also used for coating cloth or paper with plastic material.

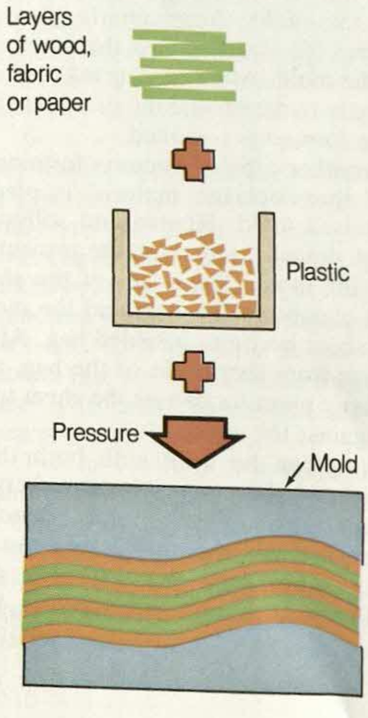
Laminating involves taking layers of wood, fabric, or paper and impregnating them with a solution of thermosetting plastic material to form strong, rigid products. The material is treated with the thermoset solution and is placed between the *platens*, or flat plates, of a laminating press. Heat and pressure are then applied.

Foaming can be done by several methods. Gas bubbles may be introduced into the melted plastic by chemical reaction, by heating a volatile liquid, or by forcing gas in under pressure. Among the plastics that can be foamed are cellulose acetate, polyethylene, styrene, urethane, vinyls, phenolics, and silicones.

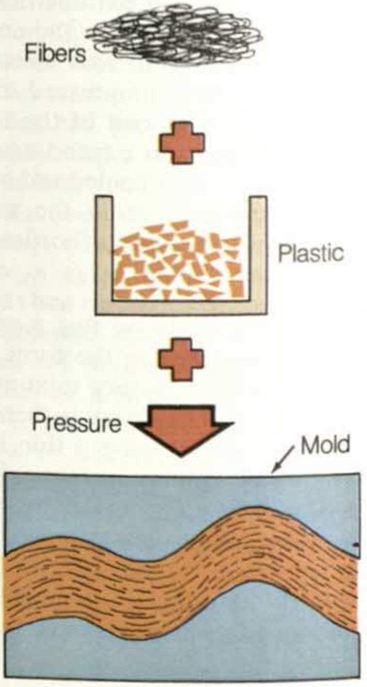
Reinforced plastics are produced by embedding various substances in certain thermosetting plastics. The reinforcing materials include glass fiber, asbestos, cord, cloth, and paper. They may be in the form of chopped fibers or of sheets. Pressure is applied to the reinforced plastic to mold it into the desired shape.

Additional operations are often required to complete the production of a finished plastic product. For example, the moisture content of molding powders must be reduced to a very small amount before the molding operation. In some cases preheating takes place. Some plastic products are preformed before compression molding. Sometimes they are annealed after molding—that is, they are heated and then slowly cooled. Annealing relieves stress that develops during molding and cooling. After the molding process, some excess plastic material is frequently attached to the molded part and must be removed in order to obtain a presentable finished product. This is often done by mechanical tumbling.

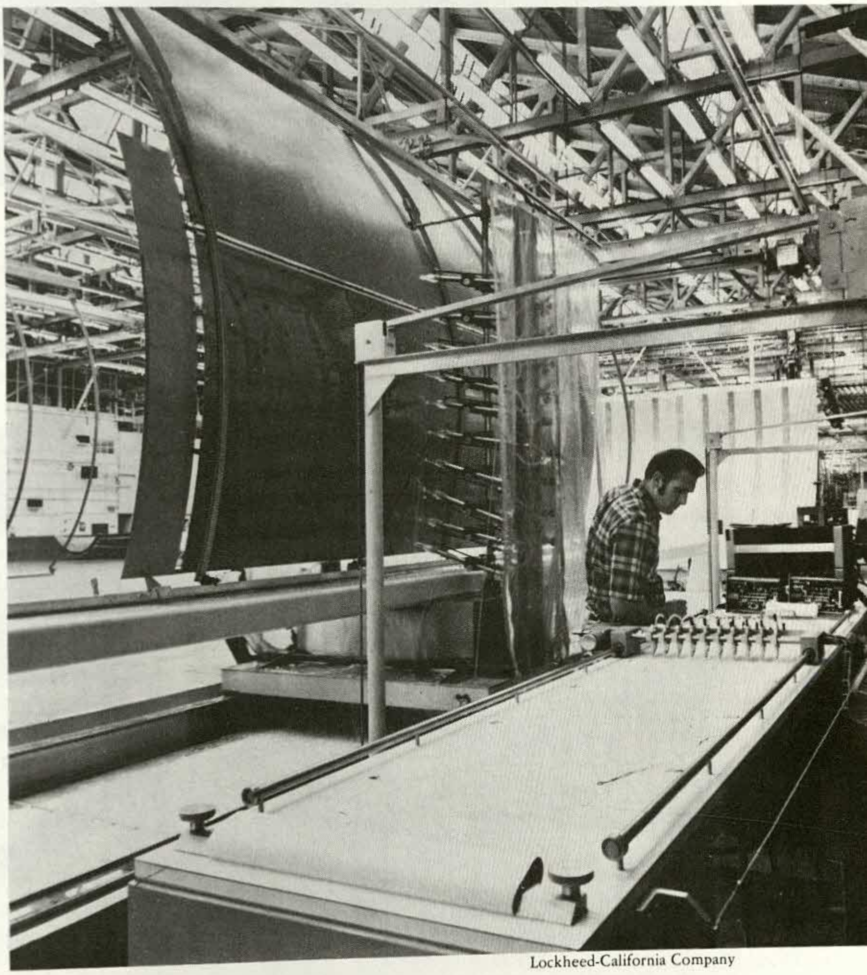
Using the processes we have just described, manufacturers turn out either finished products or semifinished products or semifinished materials, such as sheets and rods. Manufacturers called *fabricators*, employing various kinds of machine tools and other equipment, will transform the semifinished materials into costume jewelry, boxes, display signs, television lenses, raincoats, and a host of other products.



LAMINATING



REINFORCING



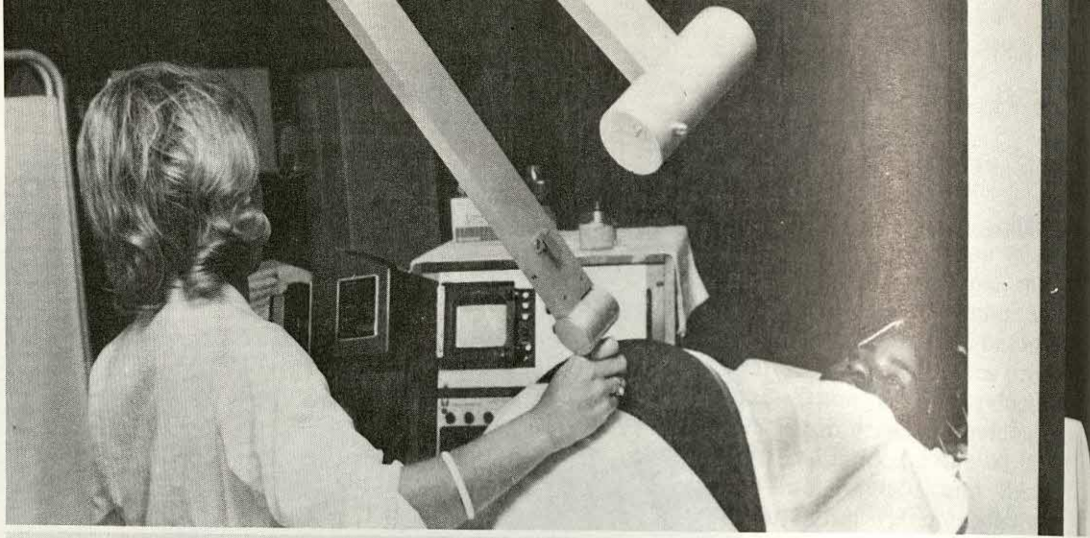
Ultrasonic waves can be used to detect flaws in such objects as airplane fuselage panels. Here, an inspector reviews the printed results of the detecting device.

Lockheed-California Company

ULTRASONICS

As you walk down a country lane at the height of summer, there is a constant drowsy murmur of humming bees, droning flies, and chirping crickets. Even as you listen intently to these faint, thin noises, the insects are making a great many other sounds that human ears cannot catch. Scientists have succeeded, however, in developing devices for detecting such "silent" sounds and also for producing them. The study of these sounds is called *ultrasonics*. The term comes from *"ultra,"* meaning "beyond," and *"sonic,"* meaning "referring to sound."

Since ultrasonic sounds differ in only one respect from sounds that we can hear, let us see first what sound is. For a sound to be created, three things must happen. First, an object must be made to vibrate, as when you press on an automobile horn, pluck a taut string, or strike a tuning fork. The rapidity of the vibration—in more scientific terms, the *frequency* of the sound—depends on how elastic and dense the object is. No matter whether it is struck hard or lightly, the rate of the vibration for that substance will be the same and is its natural frequency. This gives sound its *pitch*—its high or low tone. The more rapid the vibration, the higher the pitch.



top: March of Dimes; bottom: Bowman Gray School of Medicine of Wake Forest University, North Carolina Baptist Hospitals, Inc.

Because there is no known danger to the fetus, ultrasound is routinely used to examine high-risk pregnancies. Top: a patient is being examined with an ultrasound probe. The resulting scan shows the position and size of the fetus. Bottom: echogram of an eight-month-old fetus.

Second, as the object moves rapidly to and fro, it alternately pushes and pulls at the nearby molecules of whatever medium surrounds it, usually the air. Sound cannot be created in a vacuum. There must always be some medium—a gas, a liquid, or a solid. When the molecules are pushed together, they are *compressed*. When they are pulled, they are spread apart, or *rarefied*. Sound travels because this double motion is communicated to the molecules of the medium ever farther and farther away from the source of the sound. Thus a sound wave is a series of compressions and rarefactions in the medium through which it passes. Throughout the course of a sound wave's journey and regardless of its speed, the frequency of the sound remains the same as that of its source. The wave of motion might be compared to what happens when one pushes the last man of a long line of people waiting for a bus. The last man will have to push on the one in front of him and so on down the line. The initial push thus moves forward from the last man, carried by the people in front of him. The push travels along, but the line does not move.

Third, the sound waves must be received by some organ, such as the ear or by some mechanical device. It is like the completion of a call when your friend answers the telephone. Biologically speaking, sound is the translation in the brain of sensations received through the nerves of hearing leading from the ear.

A MATTER OF FREQUENCY

The difference between ultrasonic and ordinary sound waves is a matter of frequency. In fact, it is necessary to make this distinction only because human hearing has certain definite limits. The human ear is so constructed that even at its keenest it can register as sound only those frequencies that lie between 20 and 20,000 hertz. Any frequencies below 20 or above 20,000 are "silent" as far as humans are concerned. Ultrasonics therefore is concerned chiefly with the frequencies above 20,000 hertz.

We have said that a sound wave is a series of compressions and rarefactions. The wavelength of a sound is the distance from one compression to the next. Consequently, the higher the frequency of the sound, the shorter its wavelength. When the wavelength is comparatively long, the sound flows around small obstacles, much as a large wave in the ocean surf flows around a piling, with hardly any reflection. This ability of any kind of long wave—light and other electromagnetic waves as well as sound—to spread around an object is called *diffraction*. But with short wavelengths, the sound is reflected back, or echoed, from small objects, just as little wavelets would be tossed back from the piling. In other words, short wavelengths are diffracted less.

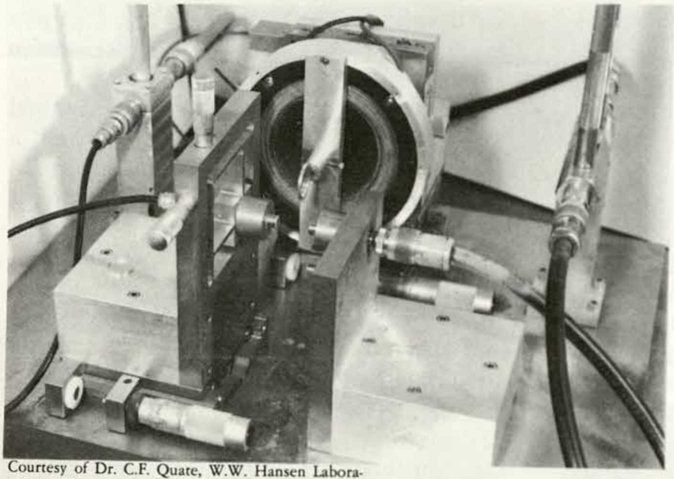
PRODUCING ULTRASOUND

Scientists have discovered several ways of producing ultrasonic waves. The one most used for sending these waves through solids or liquids depends on a peculiar property of certain crystals, such as quartz, Rochelle salt (sodium potassium tartrate), and ammonium dihydrogen phosphate. This property is called the *piezoelectric effect* (from the Greek *piezein*, meaning "to press," plus "electric"). The effect was discovered by Pierre and Jacques Curie in 1877.

When pressure, which may be applied by weights, is brought to bear on such a crystal plate cut in a certain way, the plate becomes electrically charged. The amount of current generated is in proportion to the amount of pressure applied. Moreover, if the charged plate is stretched, the charge will be reversed. By alternate compression and stretching, therefore, an alternating current will be set up. The piezoelectric effect will work in the opposite way, once the natural frequency of the crystal is known. If an alternating current of the same frequency as a crystal's natural one is applied to the crystal, it will expand and

Ultrasonics can be used to diagnose abnormalities of the heart, such as faulty valves, congenital defects, and fluid accumulation around the heart.

UPI Photo



Courtesy of Dr. C.F. Quate, W.W. Hansen Laboratories of Physics, Stanford University

The ultrasound microscope. The specimen is held in the small metal ring on the rear. It is not necessary to dye the specimens for viewing.

contract in rhythm with the changes in the direction of the current.

The scientist produces ultrasonic waves by applying electricity to a crystal. Usually, small metal plates are attached to the crystal in an ultrasonic device and they move up and down in the same rhythm. This, in turn, sets up similar vibrations in the medium in which the apparatus is immersed—often a dish of light oil. With certain crystal cuts, their length or thickness is alternately increased and decreased and the waves travel in a longitudinal direction—that is, along the direction of the beam of sound. There are other crystal cuts from which the waves travel at right angles to the direction of the beam.

Another way of creating ultrasonic waves involves the use of an iron or nickel rod. A solenoid, which is a tubular coil for the production of a magnetic field and acts like a magnet, is placed around the bar. When a high-frequency alternating current is sent through the solenoid, the bar is magnetized in such a way that there are slight changes in its length in rhythm with the alternation of the current. The vibration is communicated to the medium surrounding it. Such a variation because of magnetization is called *magnetostriction*.

The strangest feature of these ultrasonic waves is that in the range of very high frequencies they have tremendous power. Ordinary sound waves have energy, but it is usually rather weak. Even a million persons all talking steadily for an hour and a half in a huge hall would produce only enough sound energy, converted into heat, to produce a single cup of hot tea. Yet, in early experiments with ultrasonics, small fish swimming through the ultrasonic beams were killed instantly. When one researcher held his hand in the path of the waves—only for an instant, you may be sure—he felt agonizing pain, as if his very bones were being heated.

SONAR

As long ago as 1914, a French scientist, Paul Langevin, found a way to make use of the echoing quality of ultrasonic waves. He and his assistants built an apparatus that could send strong bursts of high-frequency sound through the water. The waves traveled in straight paths without being diffracted. When they hit a submerged rock or a submarine, an echo returned. This precursor of the detecting device known as *sonar* was a new way of detecting underwater perils.

Langevin's discoveries were refined further. A device for locating treacherous icebergs and hidden reefs was developed around 1920.

Sonar, developed during the 1940s, was a still greater refinement on the early ultrasonic underwater devices. When a pulse of ultrasonic waves is sent through the water from a ship equipped with sonar, an echo of the same frequency returns to the sonar apparatus from any solid object in the path of the waves. Since they are not diffracted, the direction from which the echo returns reveals the position of the object.

The distance, say, of a submarine from the ship can be calculated from the length of time that elapsed between the sending of the original pulse and the return of the echo. The device is able to repeat the transmitting and receiving operations many times per second, so that extremely brief periods of time are able to be measured by this means.

Sonar is helpful to navigators in making soundings. If an ultrasonic beam is aimed straight down toward the ocean bed, the depth of the water can be figured from the length of time it takes the beam to go down and be echoed back.

In 1951, Wayne M. Ross, a U.S. engineer, developed a simplified but even more sensitive sonar system. With this it is possible not only to locate schools of fish but also to identify the fish by determining the size of each school and the depth at which it is swimming. The device is of even greater importance in the navigation of narrow, rocky channels because the echoes bounce back from hidden shoals and from coastlines. The ultrasonic beam can be sent in any direction through the water, and the pattern of the echoes is displayed on a screen, much like radar. Ross's invention also records information in two other ways. The returning echoes are translated into audible sounds, over a loudspeaker, that a trained operator can easily recognize. A solid wall gives out a hard, clipped ping. Sounds from a smooth beach or a hidden sand bar are drawn out, as if someone were scratching granite with his fingernails. At the same time, automatic pen-and-ink records are made of all the echoes that appear on the screen and are heard over the loudspeaker.

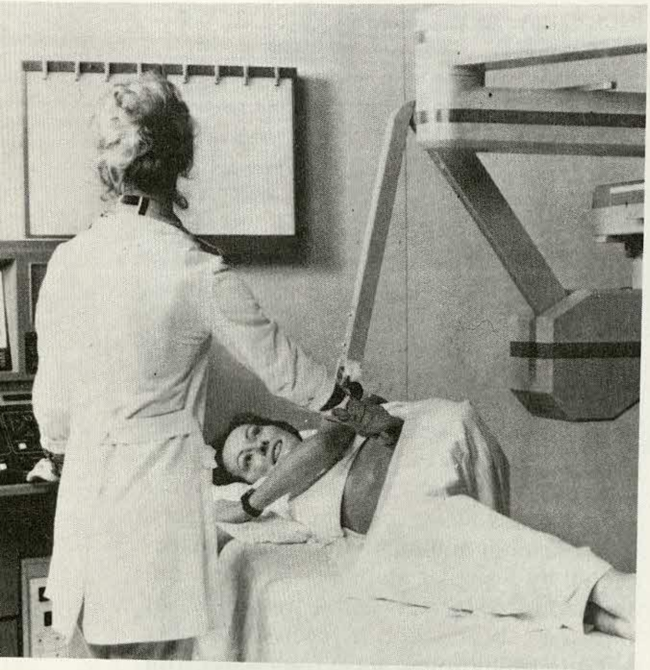
INDUSTRIAL APPLICATIONS

Both science and industry use ultrasonics. One device, called a *reflectoscope,* sends short burst of ultrasound into a metal object, such as a casting, searching out flaws. A quartz-crystal mechanism is placed against the object, with only a film of oil between them. The reflection of the high-frequency beam sent out by the crystal is picked up by the crystal, now acting as a microphone. Electronic switching is necessary, because the alternate use of the crystal as transmitter and receiver takes place in millionths of a second. Any flaws in the metal bounce back as echoes and flash on a cathode-ray screen, a kind of fluorescent screen, showing the location of the defects.

Flaws in automobile tires may be detected by a similar method. The tire is immersed in water between a transmitter of ultrasonic beams and a receiver. Rubber will transmit a sound wave from water with little reflection so that any echoes indicate a defect in the rubber.

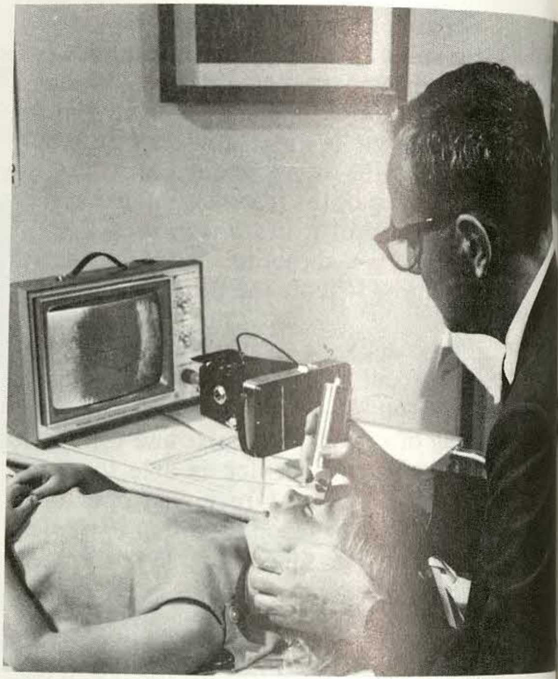
Very high-frequency sound waves can make two liquids emulsify that ordinarily would not mix. For instance, alloys of iron and lead, aluminum and cadmium, and so forth can be made to mix in the liquid state and kept mixed until they solidify. New bearing materials are being produced in this

Ultrasonics can be used to clean many materials. The next time you visit a jewelry store, check to see if they have this type of device.



Branson Ultrasonics Corporation

Ultrasonics provides better soft-tissue imaging than conventional X rays. Ultrasonics cannot, however, give a clear picture of bone.



G.D. Searle and Co.

The ultrasonic scanner can be used to detect detached retinas and any foreign objects that happen to be in the eye.

way. Another application of this effect is to make photographic emulsions stable and of the same consistency throughout.

Some kinds of chemical reactions are speeded up under the influence of ultrasonic waves. They can also break up long-chain polymers—molecules with a highly complicated structure.

Another use of high-power ultrasonics is to make solid and liquid particles in mist, dust, and smoke clump together. Factories that make lampblack, for instance, an ingredient of varnishes, paints, and some kinds of ink, use ultrasonic generators in the flues of their smokestacks. Ultrasonic vibrations push the lampblack particles together. The particles drop down the chimney instead of escaping into the outside air. Around airports and harbors, ultrasonic waves can disperse fog and mist. It is even possible that large industrial areas overhung with palls of smoke and soot may be cleared by the same method.

Quicker and better laundering is another very practical use of ultrasonics. The intense vibrations break down the attraction between dirt particles and fabrics and shake the grime loose.

In 1950, a U.S. patent was issued for an ultrasonic device that helps blind persons to avoid obstacles. The waves are sent out from a mechanism in a walking cane. Echoes from any object ahead are picked up by a receiver in the cane. Their energy is converted into electric pulses that travel by wire to the person's ear where, by means of a kind of microphone, the pulses are translated into audible sound.

Ultrasound can be used to weld certain metals, plastics, and fibers. It can also be used to clean lenses, jewelry, tarnished metals, surgical instruments, and various other materials.

Ultrasound has been widely used to monitor various industrial processes. Gauges based on the action of ultrasound have been developed to measure thickness, size, pressure, concentration, and density.

BIOLOGICAL AND MEDICAL EFFECTS

In much the same way as it is used to detect structural flaws, ultrasound can be used to detect flaws in living tissue. The reflective properties of normal and abnormal tissues differ enough to allow them to be distinguished ultrasonically. An ultrasonic scanner can detect certain malignancies in their early stages. This diagnostic tool has been used to discover malignancies in the breast, liver, brain, and several other organs. Ultrasonic scans of a pregnant woman will show the fetus in the uterus. To minimize the risk to healthy tissue, low-intensity ultrasound is used in these types of diagnoses.

In some kinds of surgery, high-intensity ultrasound can take the place of scalpels. Ultrasonic surgery is especially promising in the fields of neurology and otology. There has been some success in the treatment of Meniere's disease, an ear disorder.

The ultrasonic drill has been applied to dentistry. The advantages of the drill lie in its simple and painless cutting of hard tooth material. However, it is not effective on decayed tooth material. Ultrasonic devices have also been used to clean teeth.

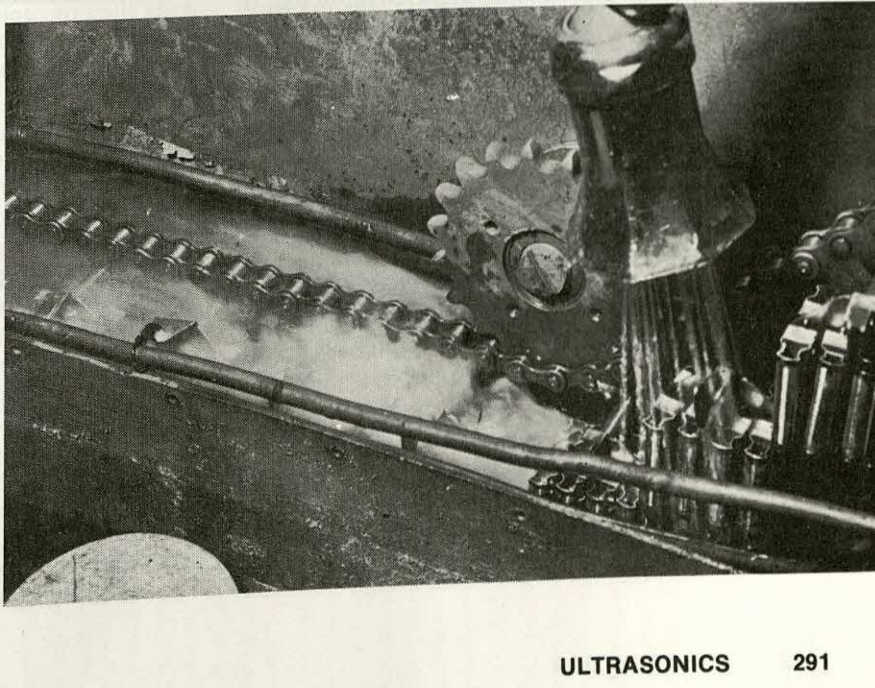
The use of ultrasound may have applications in agriculture. Seeds and seedlings irradiated with low-intensity ultrasound germinate faster than untreated seedlings and seeds. In one case, it was reported that potato plants so treated blossomed a week ahead of time and their yield increased 50 per cent above the crop from untreated plants.

It seems that the beneficial effects may be due to decreased rigidity in the plant cell walls and an increased uptake of water. Vital chemical reactions that cause germination may also be speeded up by the action of ultrasound.

However, ultrasound can have a harmful effect on living systems. It has already been pointed out that small animals exposed to high-intensity ultrasound will often die. People working with ultrasonic generators over long periods of time suffer fatigue and nausea and sometimes disorientation.

Plants, too, while responding well to low-intensity ultrasound, can be destroyed by higher intensities. Besides cellular damage, ultrasound can also harm genetic material in the cell.

The study of ultrasonics is an expanding field. Knowledge of the hazards of this powerful tool will be important in developing guidelines for future research and industrial and biological use.



General Electric

This ultrasonic bath cleans shaver heads for electric razors.

FIBER OPTICS

It has been known for many years that light can be transmitted through a hollow pipe, even if the pipe is curved. Light entering one end of the device is reflected again and again from the inner walls. It makes its way down the pipe and at last emerges at the far end. A device of this sort can be made from highly polished silver or aluminum. It has no practical applications because it is not very efficient. There is some loss of light every time the light rays are reflected. In a pipe in which the length is many times the diameter, many reflections will take place, and there will be a substantial loss of light.

Fortunately, there is a way of bringing about an extended series of reflections virtually without light loss. This can be done by having total internal reflection take place at the *interface,* or boundary, between a dense medium, such as glass, and a rare, or not-so-dense, medium, such as air. To summarize briefly here, if a ray of light passing through the glass is refracted, or bent, by more than a certain angle, it will not leave the glass at all. It will be totally reflected again and again from the interface (Fig. 1). There will be a minimum loss of light as the rays make their way through the device.

A light pipe of this sort is really not a pipe in the ordinary sense of the term, but a solid rod. All light pipes commonly used today are of this type. They have been made of glass and of transparent acrylic plastic. Glass is now the preferred material being used.

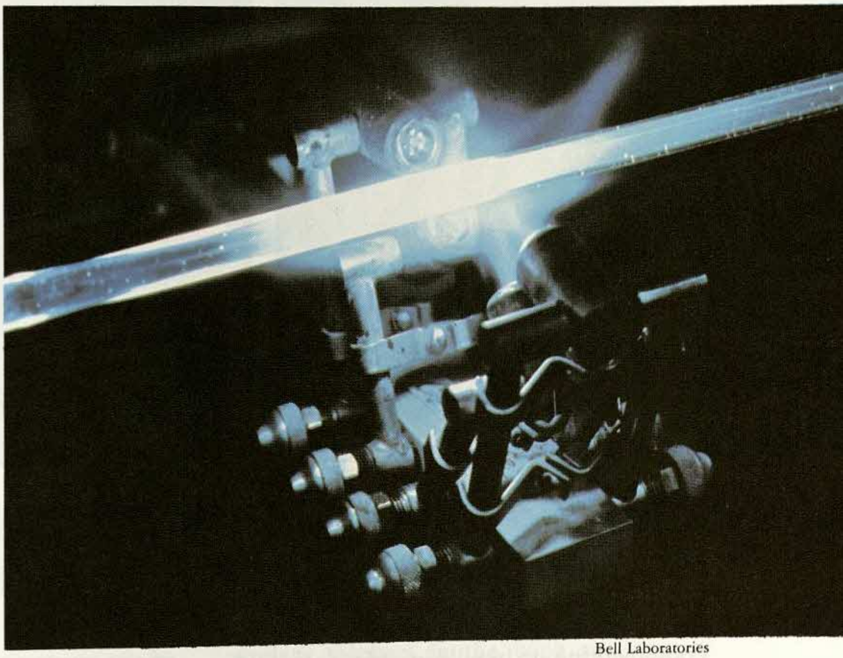
TRANSPARENT PIPES

A light pipe consisting of a single glass or plastic rod will convey light energy but it will not transmit an image. Let us see why. When we look, say, at a postage stamp, we see it because the light reflected from it reaches our eyes. This light is reflected from different areas of the picture with different degrees of intensity. Thus there will be less light from a dark area, more light from a light area. This varying intensity makes up a definite pattern. If the light waves from a given area of the picture pass through a single light pipe with a diameter of, say, one centimeter, they will follow a variety of paths as they make their way through the pipe. By the time these light waves and the light waves from the other areas of the picture reach the other end of the pipe, the image will be so mixed up as to be unrecognizable.

DuPont Company

A fountain of light from the new world of optical fibers: an imaginative use of fibers—here, made of plastic—produced this display.

To convey an image, a great many light



To produce an optical fiber, a tube of fused silica is heated to a high temperature. Silica and other glass-forming oxides are deposited on the inner walls of the tube.

Bell Laboratories

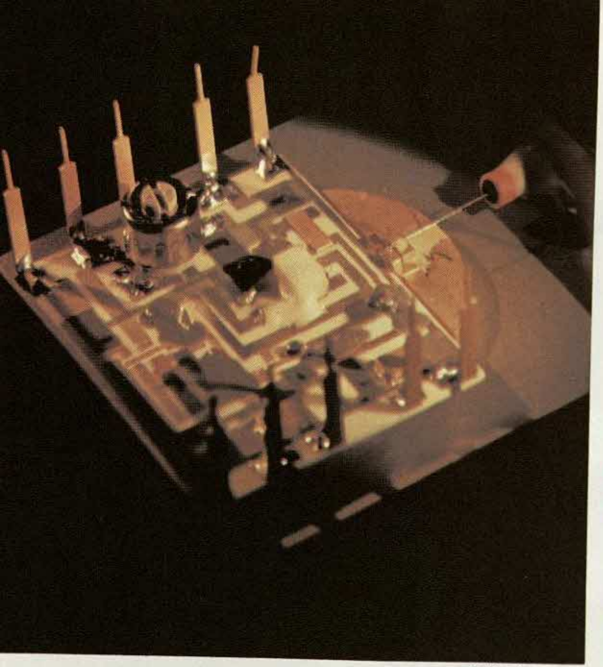
pipes must be used in combination (Fig. 2). The image is divided into a number of small areas. The light from each of these small areas is carried through an individual light pipe to the corresponding point in the image at the other end of the bundle of pipes. The diameter of each of the glass or plastic rods combined in this way has been so greatly reduced that it is appropriate to call such rods *fibers*. A device in which a number of fibers are combined in order to transmit an image is called a *fiberscope*. It forms the basis of the science of *fiber optics*.

FIBERSCOPE

Obviously, a flexible fiberscope would be able to transmit images around a corner. The idea of making such a device must have occurred to many students of optics in the last hundred years or so. However, there seemed to be insurmountable difficulties. For one thing, if simple fibers were in contact, light would leak from one fiber to another, causing a distortion of the image. Again, the surfaces of the fibers would become scratched as they came in contact. There would be loss of light at the scratched places.

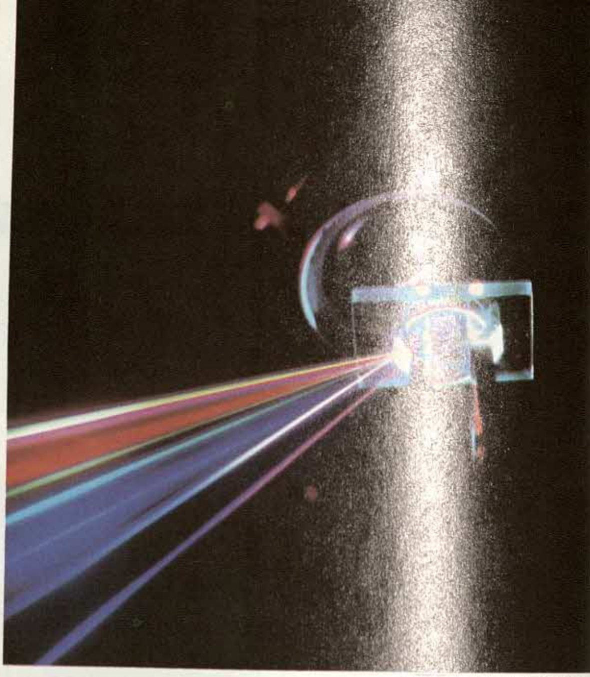
Experimenters overcame these difficulties in the 1950s by creating a fiber consisting of two parts: an *inner core* and an outer coating, or *jacket*, both transparent. The inner core has a high index of refraction. The coating that surrounds it has a low index of refraction. The index of refraction of a given medium is the ratio of the velocity of light in a vacuum to the velocity of light in the medium. The higher the index of refraction, the less the velocity of light in the medium. The total internal reflection takes place at the interface between the high-index and low-index material (Fig. 3). Thus the reflecting surface is sealed in and kept away from other reflecting surfaces. There is practically no light leakage and no light loss due to surface scratches. Fibers of this type are found in virtually all fiber-optics devices in use today. Generally the fiber bundles in which they are combined are provided with flexible sheaths of metal or plastic.

If an image is to be formed, the relative position of the different fibers must be the same at one end of the fiberscope as at the other end. The fibers need not be so precisely arranged elsewhere in the device. They can be left more or less loose and flexible. A great many fibers will have to be



Bell Laboratories

The transmitter of a lightwave communications system. A beam of laser light is seen entering the transmitter from the right. Optical-fiber systems will be able to handle a greater number of telephone calls and TV programs than present system can.



T. Cook, RCA Laboratories

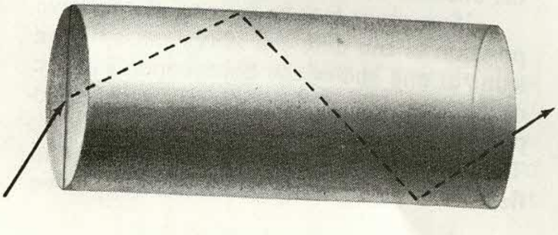
A thin-film waveguide using optical fiber is seen transmitting three laser beams of different colors at the same time. Advances in laser technology are also an important part of the rapidly growing potential of fiber optics.

combined in one bundle in order to provide a satisfactory image. In a commonly used type of fiberscope, there are about 750,000 fibers, each being 0.001 centimeters, or 10 microns. For certain applications, the diameter of the fiber may be as small as five microns—the minimum size.

FLEXIBLE LIGHT GUIDES

In some cases, it is not necessary to transmit an image through a fiber bundle, but only to transmit light. A device of this sort is not called a fiberscope, but a *flexible light guide*. The fibers in such a bundle can be arranged at random. The bundle is called *incoherent*, in order to distinguish it from *coherent* bundles, which transmit images. It is easy to make incoherent bundles, and they are much cheaper than coherent bundles of the same dimensions.

Fig. 1. How light is totally reflected at the interface (that is to say, boundary) between glass and air in a light pipe.

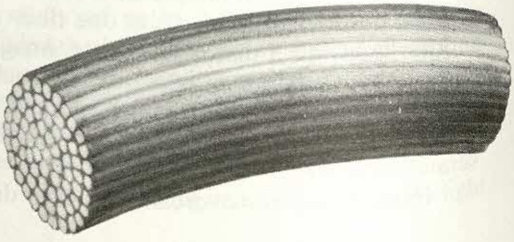


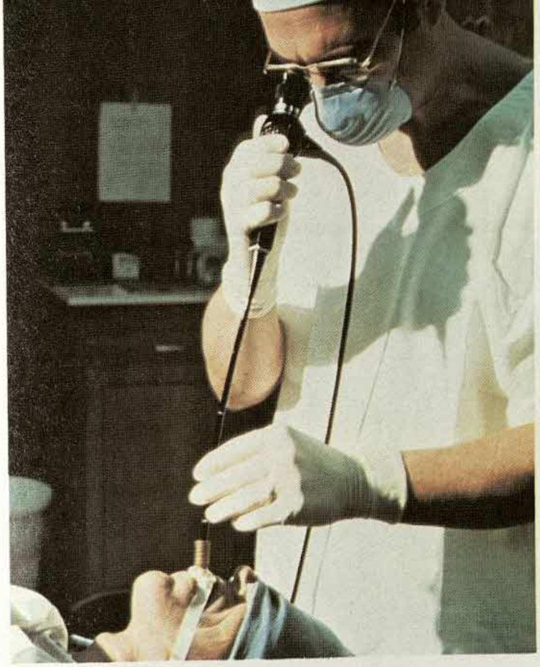
APPLICATIONS

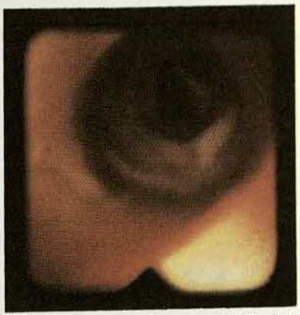
Fiber-optics products have already found a host of applications. Flexible light guides are used to provide illumination for delicate surgery. They also serve to light up instrument panels and to detect fire in hard-to-get-at places.

Fiberscopes have a far wider range of applications. Physicians, for example, can see the inside of the stomach through a *gastroscope*, an instrument based on the use of optical fibers. Similar instruments are used to view other internal organs, such as the

Fig. 2. Combining light pipes to form a fiberscope. A fiberscope has many more light pipes than are shown below.







Both photos, Mayo Clinic

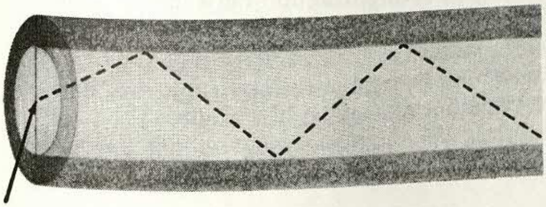
A physician performs an examination using a flexible bronchoscope. A tube of optical fibers is inserted into the trachea in order to enable the physician to carry out a direct examination of the structure within the patient's body.

A view of a normal trachea, as seen with the bronchoscope. Other instruments, based on fiber optics, have extended the physician's eye into the deeper parts of the body, making it possible to view them in their normal functions.

bladder, uterus, and colon. Surgery can be done using modified fiber-optics instruments. A miniature probe in the shape of a hypodermic needle has been developed for viewing muscle fiber, skin tissue, and blood cells. Truly, the fiberscope offers exciting possibilities in the field of medical diagnosis.

The device has also found wide use in industry. It serves for the inspection or control of operations in inaccessible areas. With the fiberscope, one can examine turbine blades, boiler tubes, and various parts of nuclear reactors for flaws and cracks. The fiberscope has been used to check fuel-level indicators in gasoline tanks after these indicators have been installed. Tools left by careless workers in the wing sections of airplanes have been unerringly spotted by the device.

Fig. 3. How light is transmitted by total internal reflection through a clad fiber. The latter consists of a transparent inner core and an outer jacket.



Bundles of fiberscopes, fused together in a solid plate, called a *faceplate,* have been used in television picture tubes and in other cathode-ray tube devices. The faceplate transfers images formed on the internal phosphor surface inside the tube to the screen, or face, of the tube.

What promises to be the most far-reaching application of fiber-optic technology is its use in communications. Optical fibers are already used to carry messages in regular telephone service. Such light-wave communication is effected by electronically breaking the voice down into thousands of pulses per second. The pulses, each with its own amplitude, are then converted into a binary sequence of ones and zeros that cause a transmitting laser to send coordinated pulses of light through the optical fiber. At the receiving end, the light pulses are converted to electrical signals and the voice message is reconstructed.

These are only a few of the ways in which devices based on fiber optics have been used. Because of its great versatility, we can expect a flood of new applications of fiber optics in the years to come.

Hoffman-LaRoche, Inc.

Liquid crystals are unstable molecular arrangements. Liquid crystals painted on the skin will change color depending on body heat.

LIQUID CRYSTALS

Walls that become transparent or opaque with the flick of a switch . . . Television sets no thicker than a picture frame . . . Coatings placed on a patient's skin to reveal underlying tumors . . . Lighted sign-boards that can be read easily, even in glaring sunlight . . . These are only a few of the possibilities in the new world of *liquid crystals*. Some of them are happening right now. Some may come true in the near future. Liquid crystals are already being used in many clocks, watches, and calculators. Some hospitals use them to monitor temperatures. Before long, liquid-crystal signs may be familiar sights along our highways, and in time liquid-crystal walls may become quite common in our buildings and homes.

HALFWAY STATE

What are liquid crystals? The words do not seem to go together. Crystals are generally solid and rigid, whereas liquids are not. To understand how a liquid can also be a crystal, we have to look at how molecules in both liquids and crystals are arranged. In a crystal, molecules are arranged in a very orderly way. They are locked into a rigid structure by electrical forces between the molecules. In a liquid, the molecules can move around freely. A liquid has no structure. It takes the shape of its container.

In a liquid crystal, molecules behave in both ways. Though they can move around freely, the molecules tend to remain in large groups. Thus a liquid crystal is usually thick and flows slowly. This is because the molecules are rod-shaped and have strong opposite electrical charges at either end. The electrical attraction between the molecules tends to keep them "lined up" in definite patterns, even in the liquid state. The more the molecules line up, the more crystalline the material becomes. The material is most like a crystal when it is spread out in a thin sheet. Then there are only a few layers of molecules, which are lined up so rigidly that they hardly move at all.

HOW THEY BEHAVE

Liquid crystals are important because of their resemblance to both liquids and crystals. A crystal does different things to light, depending on how its molecules are arranged. It may be transparent or opaque. It may reflect light, send it in different directions, or break it up into many colors. A liquid crystal can do the same things, depending on how its molecules are arranged. But it can also change very easily in the way it reacts to light. For example, a liquid crystal may be transparent one moment and opaque the next. Or it may be a single color one moment, and may show several different colors in the next moment.

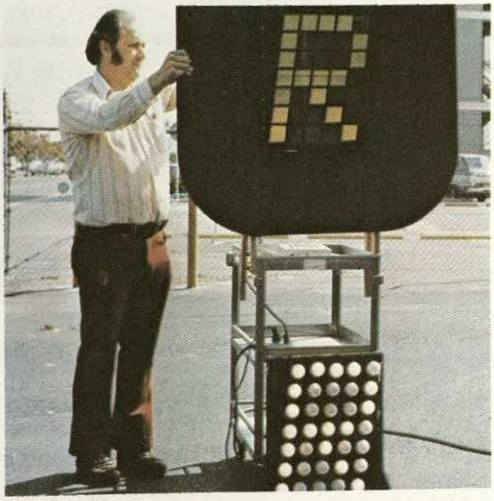
The reason a liquid crystal can change so quickly is that it is unstable. It lies on the borderline between liquid and solid, and its molecules are easily changed from one arrangement to another. The new arrangement may reflect light in a different way or not at all. Many things can bring about such a change. A small rise in temperature, a slight electric current, a small change in pressure—any or all of these factors can affect a liquid-crystal material.

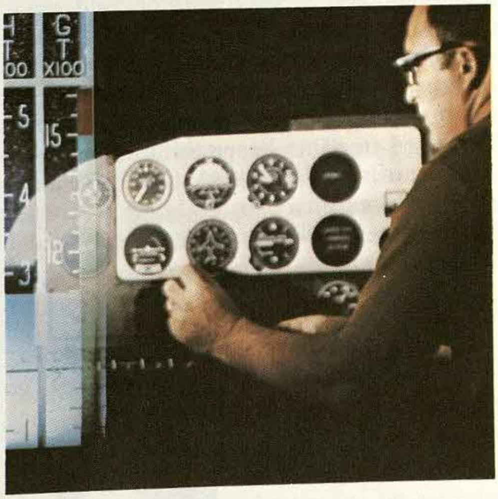
USES

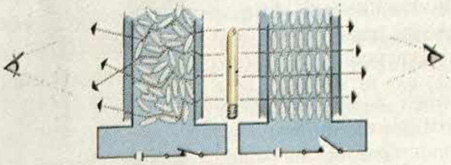
This is where a scientist can step in. If a scientist can control the changes that take place in liquid crystals, there are many ways of putting these materials to work.

For example, suppose that a liquid crystal is placed between two panes of glass, like jelly between two slices of bread, to make a sandwich. The molecules of the liquid crystal line up in an orderly way, and light passes through the material without any trouble. That is, the sandwich is transparent. But if a small electric current is passed through the liquid crystal, its molecules break apart. Now light is scattered and the sandwich becomes opaque.

Or suppose that the electric current is applied only to certain parts of the liquid crystal in this sandwich. The parts may be shaped like letters or numbers. When the current passes through them, they become

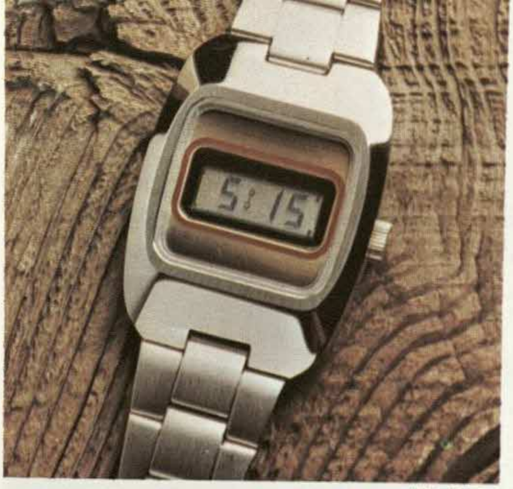






top, bottom: Rockwell International, Microelectronics Division
middle: Liquid Crystals Industries, Inc., Turtle Creek, Pa.

Top: liquid crystals make easy-to-read signs. The upper sign is made of liquid crystals. Sun glare fades the image of the electric sign just below it. Middle: liquid crystals are used in modern airplane instrument panels. Bottom: diagram showing how electric current scatters crystal's arrangement.



Optel Corp.

Liquid crystals are used in many digital readout watches. The numbers are very easy to read.

opaque and "spell out" the letters or numbers. Many ways of using this property of liquid crystals have been devised.

Some liquid crystals are especially sensitive to temperature changes. They reflect or absorb different colors according to the amount of heat they receive. Such crystals are used in some hospitals to monitor the temperatures of babies. A disk of the material is placed on a baby and then read a few minutes later. Different colors indicate high or low temperatures.

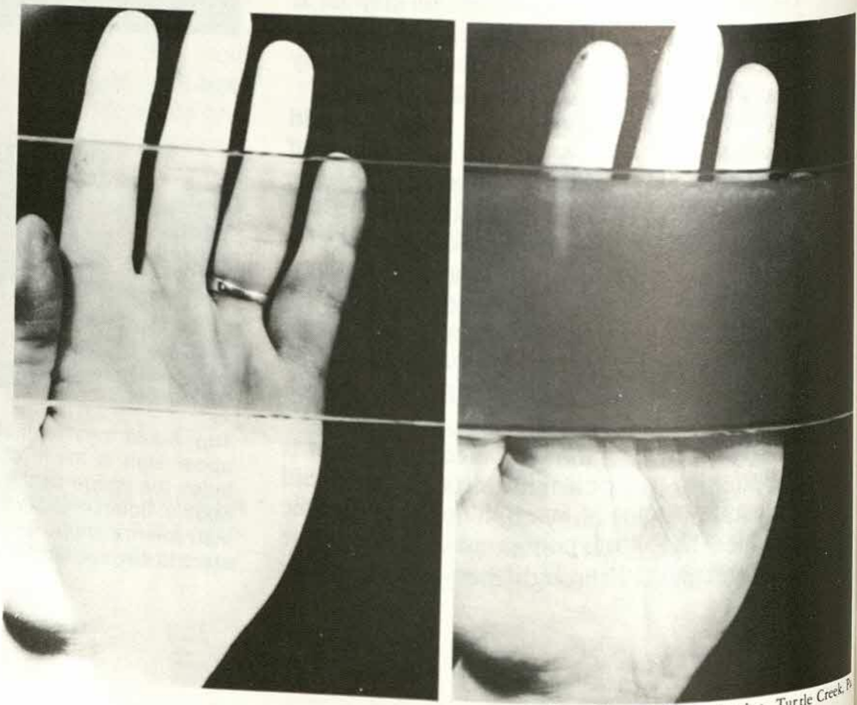
THE FUTURE

Liquid crystals seem strange and new, but they are not. Many substances go through a liquid-crystal phase as they change from solid to liquid. All of them are organic compounds. The most familiar liquid crystal is the soap bubble. The rodlike molecules of soap line up in an orderly way on the bubble's surface, holding it together.

The true nature of liquid crystals has been known for almost a century. The materials were named in 1889 by a German physicist, Otto Lehmann. Since then they have often been studied, but for a long time they seemed to have no practical use. Only in the mid-twentieth century, after other technological advances had been made, did scientists think of putting liquid crystals to work.

Many problems remain in liquid-crystal technology. For example, because liquid crystals are so sensitive to change, they are very hard to control. They also tend not to last very long. Other advances, such as the flat television set mentioned at the beginning of this article, depend on advances in other fields of technology as well. Nevertheless, liquid crystals have come to be used in several ways, and they are of increasing interest in a number of scientific fields. For example, it appears that many parts of the human body, such as the material surrounding the nerves, are in fact liquid crystals. On the research front as well as in the area of technology, the world of liquid crystals has much to offer.

Homes of the future may have walls made of liquid crystal glass panels that change from transparent to opaque at the flick of a switch. An electric current changes the molecular arrangement of the liquid crystal, bringing about the change.



Liquid Crystals Industries, Inc., Turtle Creek, P

MICROSCOPES

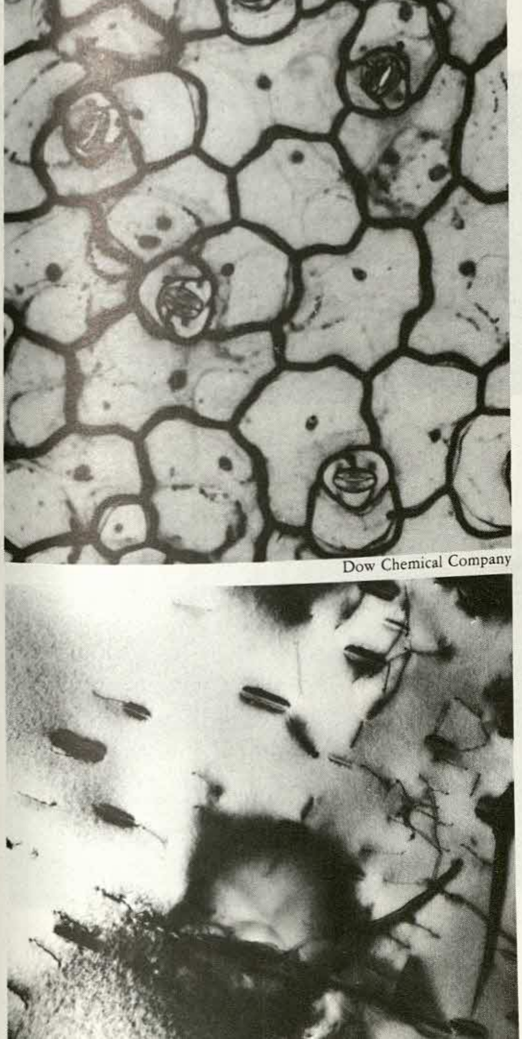
by George L. Clark

The science of microscopy began perhaps when some prehistoric ancestor of ours picked up a rounded piece of rock crystal or volcanic glass and saw that objects were enlarged by it. We know that for thousands of years man has sought to extend his powers of vision by means of devices that magnify the objects that he sees. Ancient engravers in the Middle East used glass globes filled with water to magnify the objects that they were carving. Spheres of rock crystal were used in the same way. Simple reading lenses were common during the period of the Roman Empire. Progress in the field was slow in the ages that followed, yet by the end of the sixteenth century lens grinding had become quite an advanced art.

The optical microscope was first developed near the end of the 16th century. The first crude instruments were refined over the centuries until the optical microscope could reveal scenes like the one at top: the underside of a leaf, showing stomata, or openings. Even more powerful are the nonoptical microscopes. Bottom: a metal under an electron microscope.

CCM—General Biological Supply, Inc.

Dow Chemical Company



Near the end of the sixteenth century, a great breakthrough occurred when Dutch opticians combined several lenses to make the first known compound microscope. Improvements in lenses and the design of instruments continued in the following years and on into the present. The science of microscopy is as progressive today as ever. In 1953, for example, a Nobel Prize in physics was awarded for the development of the phase microscope, discussed later in this article.

Until comparatively recent times, the only devices for magnifying small objects or the details of larger objects were optical microscopes, which depended on the use of visible light, a form of radiation. These instruments are still widely used. They have been supplemented, however, by various types of nonoptical microscopes, based on other kinds of radiation, such as X rays, ions, and electrons, and based on ultrasound. These devices have provided far higher magnifications than were previously possible. With certain instruments of this type we can even see individual molecules and atoms!

In this article, we shall discuss some of the more important types of both optical and nonoptical microscopes.

OPTICAL MICROSCOPES

With a few exceptions, optical microscopes are based wholly or partly on the *refraction*, or bending, of visible light. This refraction occurs when light passes from one transparent medium to another transparent medium, which is denser than the first. The light rays are slowed down. When they emerge from the second medium, they follow a path that is different from the original one. In optical microscopes, this refraction of light is used to form a magnified image.

LENSES

The name *lens* is given to a transparent medium that causes the refraction of light. This medium is generally made of glass, though transparent plastic has also been used. There are various types of lenses.

The *biconvex* lens, which has two convex surfaces, is thicker at the center than at the edges. Light rays passing through the lens parallel to the axis converge, or come together, at a point beyond the lens, as shown in Figure 1. This point is called the *principal focus*. The distance from the principal focus to the center of the lens is the *focal length*. Since the light rays are made to converge, the lens is referred to as a *converging lens*.

The *biconcave* lens has two concave surfaces. It is thicker at the edges than at the center. When light rays parallel to the axis pass through the lens, they diverge, or spread apart. If we follow these diverging lines back through the lens, as shown by the dotted lines in Figure 2, they seem to meet at a point on the same side of the lens as the source of light. This point is the principal focus of a biconcave lens. The distance

Fig. 1. When light rays pass through a biconvex lens parallel to the axis, they meet at the principal focus. The distance from the principal focus to the center of the lens is the focal length.

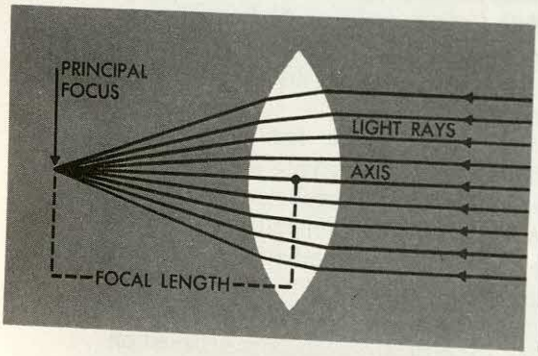


Fig. 2. When light rays pass through a biconcave lens parallel to the axis, they diverge. If they are followed back through the lens (dotted lines), they seem to meet on the same side of the lens as the light source.

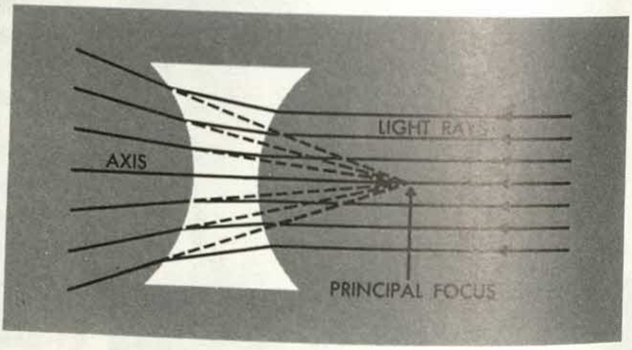


Fig. 3. The centers of curvature of the two surfaces of either a biconvex or a biconcave lens are on different sides of the lens.

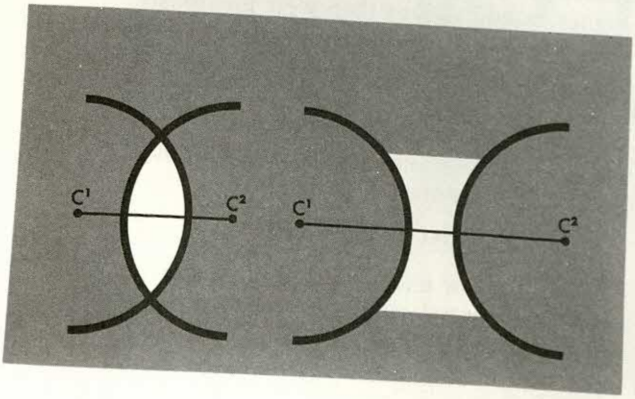
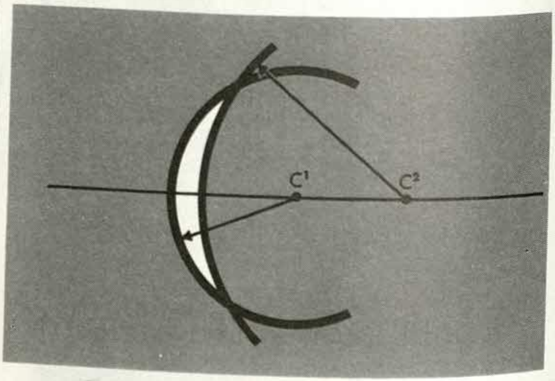


Fig. 4. The centers of curvature of the two surfaces of a meniscus lens (shown in the diagram) are on the same side of the lens.



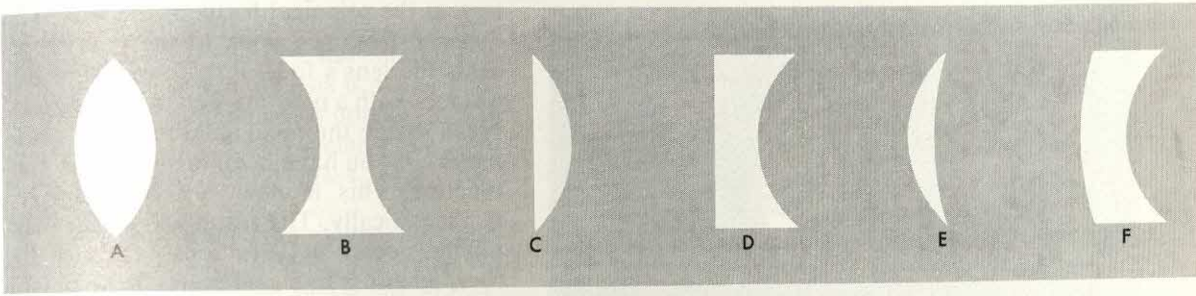


Fig. 5. The six principal types of lenses. A. Biconvex. B. Biconcave. C. Plano-convex. D. Plano-concave. E. Converging meniscus. F. Diverging meniscus.

from the principal focus to the center of the lens is the focal length. This type of lens is called a *diverging lens*.

The curved surfaces of both the biconvex lens and the biconcave lens are parts of spheres whose center is called the *center of curvature*. In biconvex and biconcave lenses, the centers of curvature of the two surfaces are on different sides of the lens (Figure 3). In the so-called *meniscus lenses*, the centers of curvature are on the same side of the lens (Figure 4). Certain lenses have one plane, or flat, surface. If the other surface is convex, the lens is said to be *plano-convex*. If the other surface is concave, the lens is *plano-concave*.

The six principal types of lenses are shown in Figure 5. We shall have occasion to refer to several of them in the pages that follow.

SIMPLE MICROSCOPES

Such optical devices as hand lenses, reading glasses, and jeweler's loupes are all known as simple microscopes. They have only one *stage of magnification*—that is, only one lens system, which may be made up of a single lens or of several lenses, joined together.

The familiar simple microscope known as the *hand lens* generally consists of a single biconvex lens. When this lens is focused on an object, no image will be produced if the object is at the principal focus of the lens—that is, a focal length away from the lens. Figure 6 shows what happens when the object is at a distance of more than one focal length from the lens. The rays of light pass through the lens and then focus on the object along an imaginary plane more or less parallel to the plane of the lens. The observer looking through the lens at the object sees an image that is on the same side of the lens as the observer. The image is inverted. It is called a *real image*, because it can be projected onto a screen held at the plane of focus on the same side of the lens as the observer. The real image is also known as the *primary image*.

Now you know that when you examine an object with a hand lens in order to obtain an enlarged view, the image is upright. For this to happen, the object must be placed at a distance that is less than the focal length of the lens (Figure 7). The rays of light reflected from the object pass through the lens and then diverge. No real image is formed on the observer's side of the lens. However, the human eye projects the emerging rays back through the lens whence they came (dotted lines in Figure 7). The rays then form an enlarged, upright image on the same side of the lens as the object. This is called a *virtual*, or *secondary, image*. It is not real, in the sense that it cannot be directly projected onto a screen held at the plane of focus. However, it can be photographed. Also, a virtual image can be treated like an object that can be viewed through another lens so as to produce a higher magnification

You can put to the test the optical phenomena described above by a simple demonstration with your hand lens. Hold the lens about one-third of a meter from your

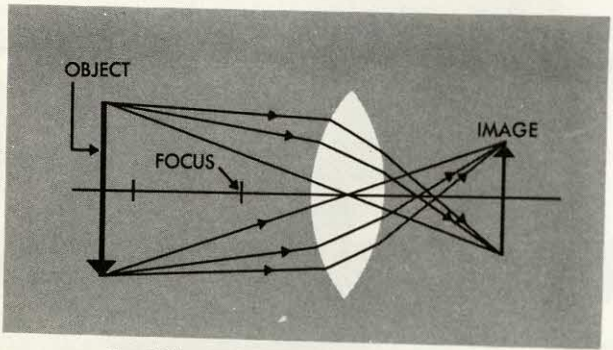


Fig. 6. The object (arrow) is at a distance of more than a focal length from the lens. The image is real and inverted.

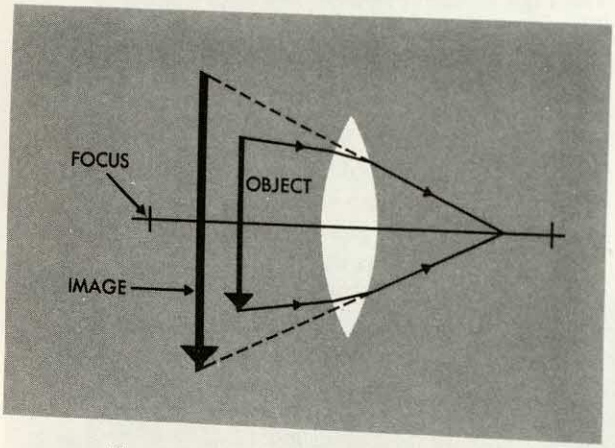


Fig. 7. The object (arrow) is at a distance of less than a focal length from the lens. The image is virtual and upright.

eyes and look through it at an object almost touching the lens. Then slowly move the object farther away. At first you will see an enlarged upright image of the object—a virtual image. Then there will be a vague blur of light and color: the object is now a focal length away from the lens. As you move the object still farther away, the image reappears, enlarged but inverted. This is the real image.

The approximate magnifying power of your hand lens can be determined very simply. Set a book upright with its spine, or backbone, facing you. Look at the printed matter near the bottom of the spine through your hand lens. Move the lens back slowly until the image becomes a blur. The book is now at the principal focus of the lens. The distance from the book to the lens represents the lens's focal length. Measure this distance with a ruler marked in centimeters. Next, divide the focal length into 25 centimeters, if you have been measuring in centimeters. This number has been derived mathematically. The result will be the magnifying power of your lens. Thus, if the focal length is five centimeters, the magnifying power is five, since 25 ÷ 5 = 5.

LENS DEFECTS

Your hand lens has certain inherent defects or aberrations. One of these is *spherical aberration,* based on the fact that the curved surface of such a lens is part of a sphere. We assumed earlier in this article that all the rays of light that pass through the lens will meet at a common focus. This is not strictly the case. The parallel rays of light that strike the margins of the lens will fall pretty far from the focus. Spherical aberration may be reduced by decreasing the *aperture* of the lens—that is, the part of the lens through which pass rays of light reflected from the object. Another method is to use a *composite lens,* which combines converging and diverging lenses. The rays of light reflected from the object will be brought to approximately the same focus by the central region of one lens and the marginal region of the other lens.

Another inherent defect in lenses is *astigmatism.* In this, the rays of light that pass through the lens obliquely from a point remote from the principal axis of the lens do not converge at a common image point. One way of correcting this condition is to chance the shape of the lens, as is done in the case of the spectacles worn by persons suffering from astigmatism.

Still another defect is *chromatic aberration*—aberration caused by differing colors. It is particularly pronounced when an object is viewed in natural, or white light. This is a mixture of many different colors, each corresponding to a different wavelength. Each wavelength is refracted differently as it passes through a lens—a property known as *dispersion of refraction*—and this brings about chromatic aberration. The refraction of the different wavelengths is also affected by the composition of the glass of which the lens is made. Thus crown glass, a compound of potassium, will not refract the different wavelengths of light in the same way as flint glass, which contains lead.

Chromatic aberration is generally corrected by combining different types of lenses made of different materials. For example, a biconvex converging lens of crown glass is often combined with a plano-convex diverging lens of flint glass. A compound lens of this sort is called an *achromatic lens*. In the so-called *apochromatic lens*, a third lens is added. In correcting for chromatic aberration, spherical aberration is also corrected.

For hand lenses that are to be used at low magnifications for ordinary purposes, the optical defects listed above are not serious enough to prevent the formation of an image that is quite acceptable. If it is necessary to do fine work at higher magnifications with a simple microscope, some or all of the corrections described above must be made. Corrected lenses are to be found in the simple microscope called the *binocular magnifier*, in which a single lens is provided for each eye.

Magnifiers with a single lens system have distinct limitations. For one thing, a lens must have a very short focal length to yield a high power. Unless the lens is very small, the effects of spherical and chromatic aberration become so pronounced that they cannot be adequately corrected. Hence simple microscopes are not effective at magnifications much above 10×, or ten times the seeing power of the naked eye.

COMPOUND MICROSCOPES

If we are to obtain high magnification with a wide aperture in an optical microscope, we must adopt a compound optical system. In this, at least two separate and distinct lens systems are used. We find this combination of systems in the compound microscope. Basically it consists of (1) an *objective*, which is close to the object that is to be viewed, and (2) an *eyepiece, or ocular*, which is located at a considerable distance from the object and close to the eye of the observer.

The standard compound microscope. Figure 8 shows a standard compound microscope of the type often used by students. The specimen to be viewed is commonly set or mounted on a glass slide, which is often covered by a thin cover glass, or cover slip. The slide is firmly held on a flat stage, which is attached to a base or support. The rays of light entering from the side of the instrument, under the stage, are reflected upward by a mirror to a condenser. The condenser is generally made up of several lenses, which concentrate the light on the specimen. From the condenser, the concentrated light rays pass up through an opening in the stage to the specimen. Under the stage, we also find a device that controls the lens aperture—either an iris diaphragm or a rotating metal disk containing a number of different apertures. In inexpensive microscopes, there is no condenser or aperture-controlling device. Light from the external source is reflected directly from the mirror to the specimen.

The objective and the eyepiece are located in a tube, or barrel, which is supported on the same base as the stage. Several objectives of different powers are mounted on a swiveling nosepiece. Each objective can be swung into position in turn in the barrel. The objective in all good microscopes consists of at least two and generally more lenses. The eyepiece usually has two. Corrections have been made in the lens systems for the aberrations noted above.

The specimen is just outside the principal focus of the objective and therefore the lens produces a real, inverted, and enlarged image of the specimen. This image is still further magnified by the eyepiece. Since the image falls between the eyepiece and its principal focus, a virtual image is produced. The rays of light that emerge from the eyepiece and fall upon the retina of the observer's eye are divergent. The eye, however, projects these divergent rays back again to form a much larger virtual image. This image is inverted, just like the real image formed by the objective.

Through the use of control knobs, the distance between the objective and the specimen and between the objective and the eyepiece can be delicately adjusted so as to bring the specimen clearly into focus.

The total amount of magnification of the microscope is the product of the magnification of the objective and the eyepiece. Thus if the objective magnifies an object 40 times and the eyepiece magnifies it 10 times, the microscope will have a magnification of 400 ×.

It should be pointed out here that *resolution,* or *resolving power,* is as important as magnification. By resolution is meant the ability to distinguish clearly between minute and closely spaced details of structure. Suppose two lines were drawn so close to one another that a hundred thousand of them would take up only a centimeter. A microscope that could resolve the two lines—that is, that would make them stand away from each other so that they could be clearly seen—would be an instrument of extraordinary power. Magnifications of up to 2,000 ×, with good resolution, have been obtained with the very best compound microscopes. Higher magnifications could be achieved, but the inadequate resolving power would make such magnifications useless.

The binocular microscope. Various refinements have been made in the basic type of compound microscope we have just described. Thus the instrument called the *binocular microscope* has two eyepieces though it has but one objective. After light rays have passed through the objective, they are refracted by a prism so that part of them pass to one eye and the other part to the other eye. Since each eye sees the same field, presented by the single objective, the binocular microscope does not ordinarily provide *stereoscopic,* or three-dimensional, viewing. But it offers more viewing comfort than the *monocular microscope,* or microscope with one eyepiece, and has been widely adopted.

The basic compound microscope, wheter monocular or binocular, has revealed a hitherto invisible world of which the simple microscope could give us no inkling. It brings clearly to our vision one-celled animals and plants, individual cells of many-celled organisms, bacteria, fine structures of organic tissues, close-ups of textile fibers, and countless other close-ups that have made possible a clearer understanding of both living and nonliving things.

But the basic compound microscope has various limitations. The high-powered objective has an extremely short focal length and must be held very close to the specimen under examination. Not only is the final image reversed, but any movements of a specimen are also reversed. Thus if an ameba actually moves toward the left, under the microscope it will appear to move toward the right. The field of view is highly restricted. Moreover the *depth of focus* is very shallow. Depth of focus refers to the degree to which the different parts of a specimen in the vertical dimension are in focus. Where the depth of focus is shallow, only a part of the specimen will be in focus. The parts above and below this section will be out of focus. Hence when a standard microscope is used to study biological tissue, say, the specimen must be sliced very thin with a device called a *microtome*. Since a specimen prepared in this way is quite transparent, it is necessary to stain or dye it to bring out details of structure.

The stereoscopic binocular microscope. This instrument provides genuine stereoscopic viewing. The device really consists of two microscopes, each with its own objective and eyepiece. They are joined together and supported on the same base. Prisms between the objectives and the eyepieces erect the images, which are reversed in the standard microscope. Since the two eyes view the specimen from slightly different angles, the image received by one eye differs slightly from that received by the other eye. The brain combines the two images into a composite one, thus giving a three-dimensional, right-side-up view of the object under examination. This type of microscope uses reflected light instead of transmitted light. It is invaluable in dissecting biological specimens. As a matter of fact, it is sometimes called a *dis-*

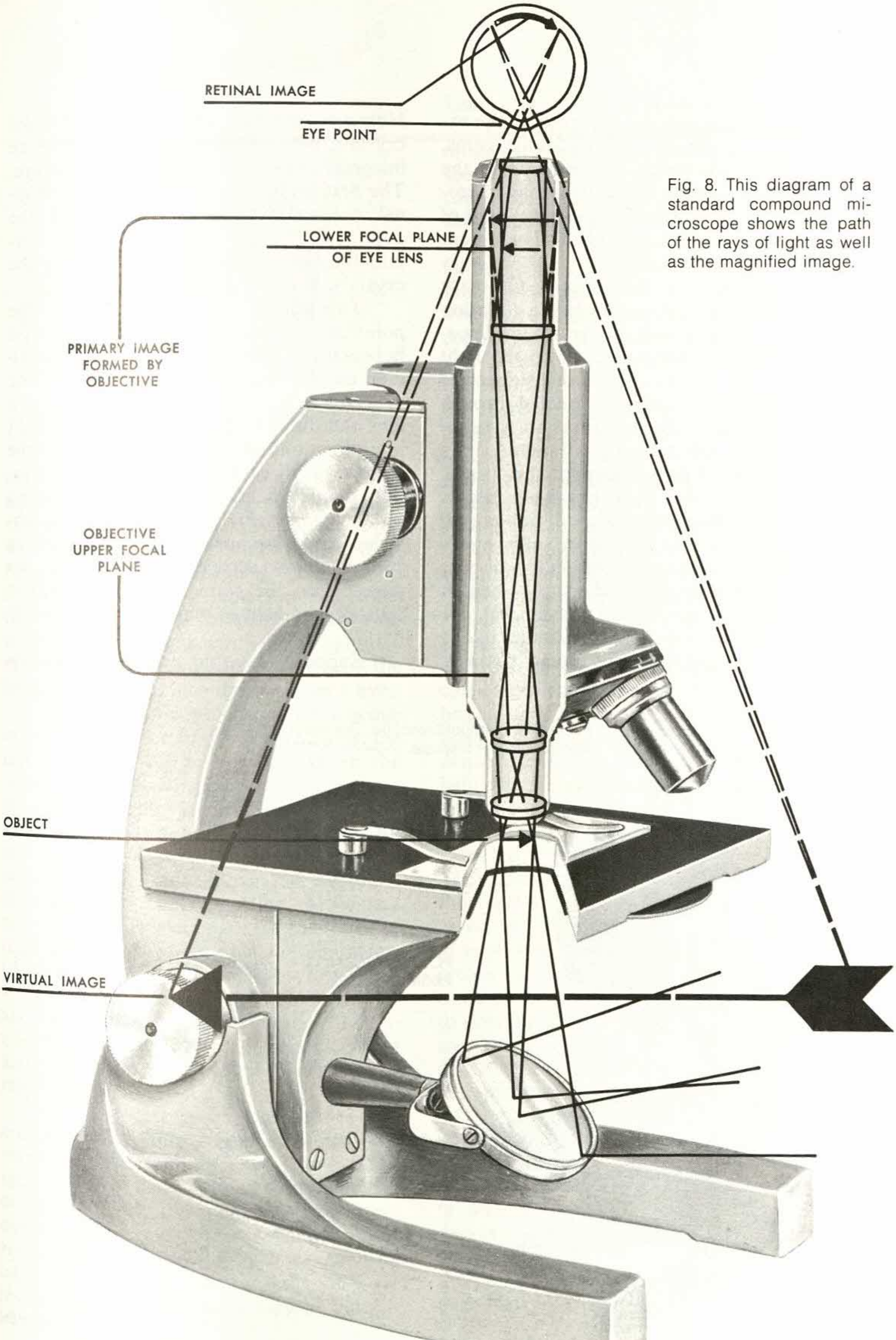

RETINAL IMAGE
EYE POINT
LOWER FOCAL PLANE OF EYE LENS
PRIMARY IMAGE FORMED BY OBJECTIVE
OBJECTIVE UPPER FOCAL PLANE
OBJECT
VIRTUAL IMAGE

Fig. 8. This diagram of a standard compound microscope shows the path of the rays of light as well as the magnified image.

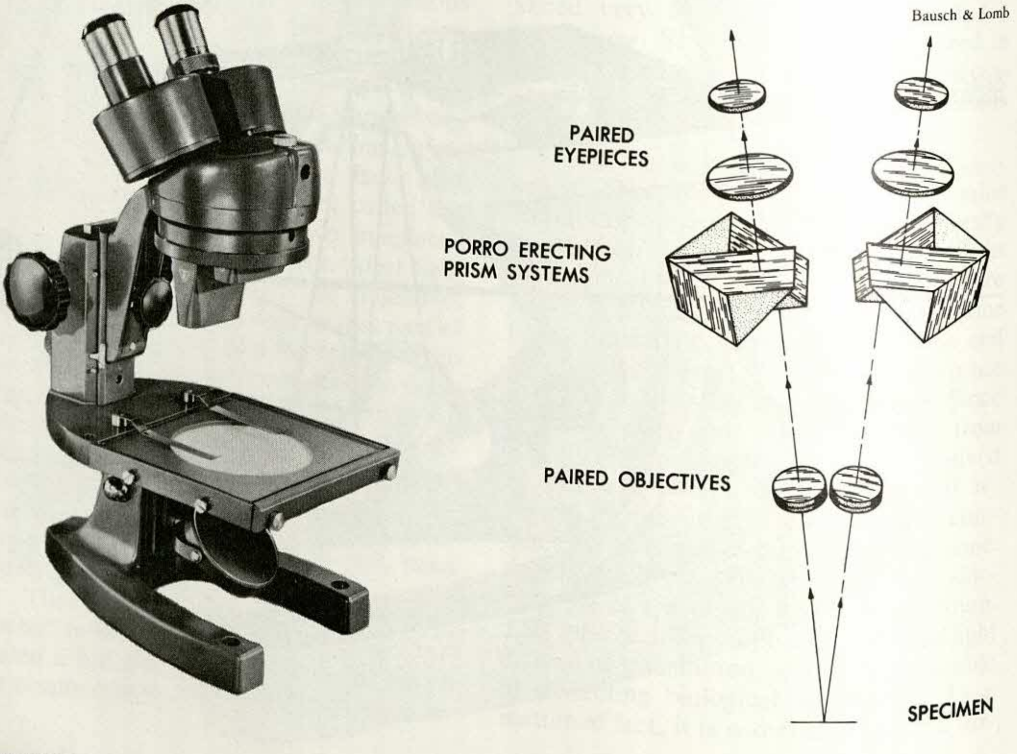
secting microscope. It also serves in the examination of objects such as fossils, gems, minerals, and coins. Unfortunately, the magnifying powers of the dissecting microscope are rather low. The practical limit of magnification in the case of this instrument is not much above 100×.

The polarizing microscope. Ordinary light vibrates at right angles to the direction in which it is traveling. It vibrates in all possible directions perpendicular to the light ray—up and down and from one side to the other. If, however, light is directed through a special prism cut, say, from a crystal of the mineral calcite, only vibrations in a single plane are passed through the crystal. We say that the light has been *plane-polarized*. If we place a second such crystal behind the first, the two can be set in such a way that the plane-polarized light will pass through both crystals and will be seen. If now we turn the second crystal 90°, the planes of vibration are perpendicular to one another and no light will come through. However, an object set between the two crystals may affect the light so that an image of the object will appear to the eye. The first crystal, which produces the original polarization of light, is called the *polarizer*. The second crystal, which permits the analysis of objects set between the crystals, is known as the *analyzer*.

This principle has been adopted in the *polarizing microscope*. The polarizer is set between the source of light and the specimen on the stage of the microscope. The analyzer is inserted between the objective lens and the eyepiece. It polarizes the light in a direction exactly at right angles to the polarizing direction of the other crystal—the polarizer. If there is no specimen on the stage, no light comes to the observer's eye, because the upper crystal has completely blocked out the light that has passed into the scope through the lower crystal. The field of view looks completely dark.

Suppose now that a specimen of crys-

The photograph shows a modern binocular stereomicroscope. The diagram shows the optical arrangement of the lenses in the microscope.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Eastman Kodak Co.

The optical microscope, using a magnification of 10 times, gives this view of a tick.

talline matter is placed on a specially mounted slide on the stage of the microscope. A visible image may appear, even with both polarizing crystals adjusted as before. This is because the specimen has affected the polarized light entering from below. It has altered the plane of vibration so that a certain proportion of the light can now pass through the upper polarizer—the analyzer—and on into the observer's eye.

The stage of a polarizing microscope is circular and free to rotate on an axis; the rim is marked off in degrees. When the stage is rotated, the specimen may become alternately bright and dark in a definite sequence. It may exhibit various colors. By relating such phenomena to the degree to which the stage has been rotated, a chemist or metallurgist can determine the optical properties of the specimen. He can then use these properties to identify and characterize the specimen on the microscope stage. It should be pointed out that some materials, such as glass and certain types of crystals, have no such effect on polarized light and so remain dark when viewed by a polarizing microscope.

The fluorescence microscope. In the ordinary microscope, the viewer sees the magnified image of a specimen through the agency of light that has been transmitted by or reflected from the specimen. In fluorescence microscopes, the specimen *fluoresces*—that is, gives off light waves of its own—when it is excited by radiation from the outside. This radiation may be certain kinds of visible light or ultraviolet.

Certain substances, including various minerals, can be made to fluoresce without special preparation. In the case of biological tissues and cells, special fluorescent stains and dyes are applied to the specimen. The radiation that causes the specimen to fluoresce does not contribute to the formation of the image but is eliminated by filters. The fluorescing part appears bright, usually colored, against a dark background.

In substances, such as minerals, that can fluoresce without special preparation, the degree and kind of fluorescence depend upon the chemical make-up of the substance. Hence the microscope helps determine its chemical composition. In materials (such as tissues and cells) that must be specially prepared with stains or dyes, the effect of the latter on a specimen provides valuable information about it. The fluorescence is sometimes analyzed by means of a *spectroscope* which is attached to the microscope.

The dark-field microscope. This device causes the object that is viewed to appear bright against a dark background. An opaque disk, called a *stop,* is set in the condenser under the stage so that no direct light will strike the specimen from below. Light reflected from the mirror under the condenser passes around the stop and is reflected from the walls of the condenser. They come to a focus upon the specimen in the form of a hollow cone of light. The result is a bright image of the specimen against a dark surrounding field. The increased contrast makes it easier to see a more or less transparent specimen and also to observe its colors. It becomes possible, too, to detect small quantities of sparsely distributed material lying on the surface of the specimen.

The ultramicroscope. This was developed long before the dark-field microscope. It is really a dark-field instrument. An intense beam of light is focused directly onto the specimen at an angle of 90 degrees from the axis of the microscope's optical system. Since no light illuminates the object from below, it appears against a dark background.

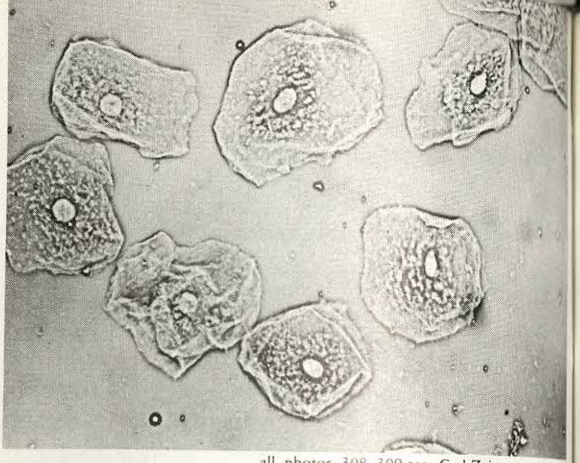
The phase microscope. Light waves are retarded in different degrees as they pass through different portions of the specimen or through the transparent slide in which the specimen is set. These differing waves are out of phase, and they interfere with one another. In the phase microscope (also called the *phase-contrast microscope*), further phase changes are introduced in the light passing through the optical system. These changes add to the phase differences created by the specimen. The resulting interference produces a high-contrast image. No elaborate staining procedure or other preparation is required for the specimen, which may indeed be a living thing.

Through the use of the phase microscope, transparent colorless crystals which do not refract light to the same degree as the liquid in which they are immersed may be clearly seen. These crystals would be too transparent to be observed in the bright field of the ordinary microscope. The phase microscope is used to study a wide variety of objects, including clay and dust, foods, fats, oils, soaps, plastics, paints, and pigments, rubber, and textiles. With this microscope, one can clearly make out the details of various types of cells or tissues that would be too transparent to be effectively studied with the ordinary microscope.

The interference microscope. This is closely related to the phase microscope. In this case, two fields, one superimposed on the other, are presented to the view. One field contains an image of the specimen and is called the *image field.* The other, the *reference field,* differs from the first in one way or another, according to the particular model. (1) It may be formed by light which has no contact with the object. (2) It may contain an image of the object which is out of focus. (3) It may contain an image of the object that has been shifted slightly sideways. Interference is accentuated by differences in light paths brought about by surface contour in the case of opaque objects by differences in thickness in the case of transparent objects. The interference microscope has been particularly useful in biological investigations.

The diatom species *Cocconeis rugosa,* magnified about 5,500 diameters. This fresh-water diatom was photographed in a dark-field microscope.

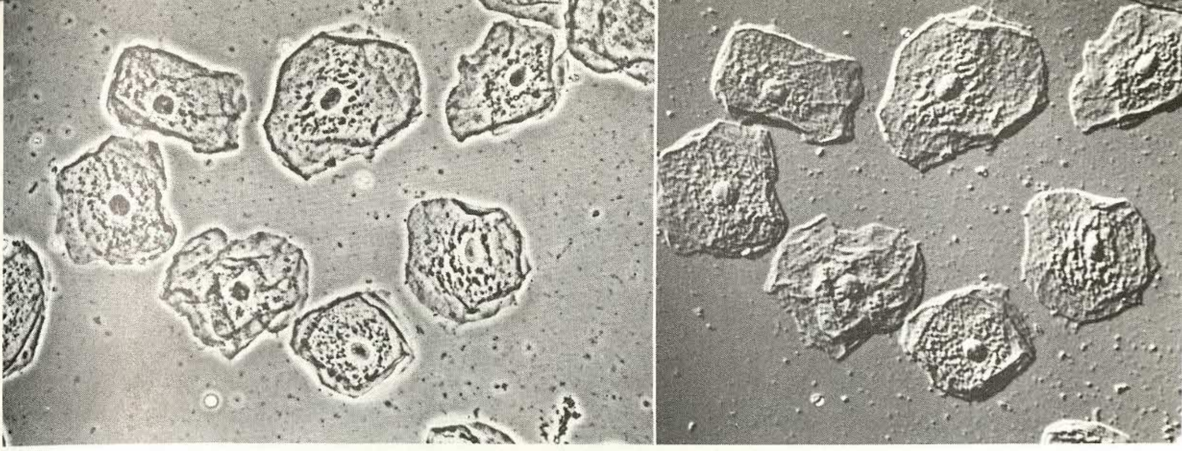
Dicalite Division/Grefco, Inc.—Richard B. Hoover



all photos, 308, 309 top, Carl Zeiss

Ultraviolet microscopes. Though these instruments use invisible ultraviolet rays, they are generally classed with optical in-

A photomicrograph of a golden diatom, *Aulacodiscus oregonus,* magnified about 1,800 diameters.

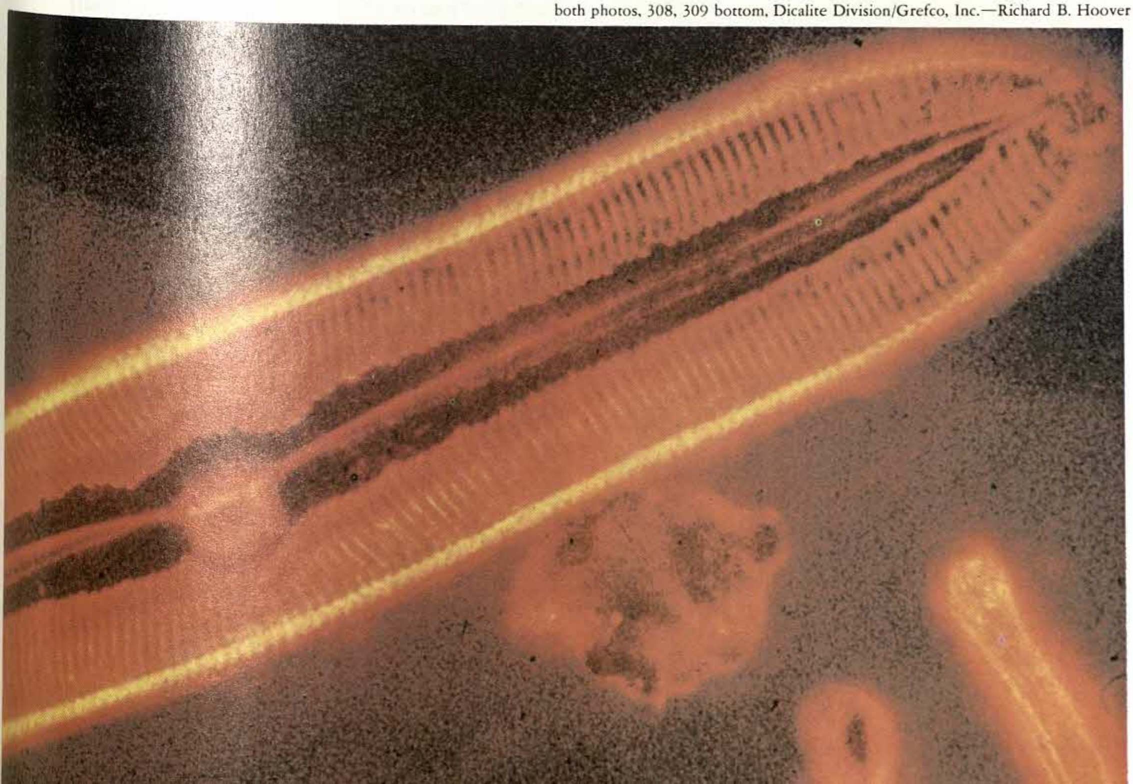


Photomicrographs of cells from mucous membranes of the human mouth, showing different kinds of optical fields. Far left: how the cells look in ordinary illumination, or bright field. There is little contrast. Middle: the same cells in a phase-contrast field. There is greater contrast, with more details showing, because light passing through the cells and the microscope are out of phase and interfere with each other. Right: Again the same cells, seen by differential interference contrast. Here surface details are brought out as the image interferes with light in a field superposed on it.

struments. The reason is that in the electromagnetic spectrum, ultraviolet radiation is next to violet, which is at one end of the spectrum of visible light. Actually, there is no clear-cut boundary between ultraviolet and violet radiation but only a gradual transition from one to the other, as is the case with other wavelengths.

In the ultraviolet microscope, ultraviolet rays serve to form an image of the specimen. The invisible image is converted into a visible one by a fluorescent screen, or a special television tube, or an ultraviolet-sensitive photographic film.

The source of ultraviolet rays is usually a mercury-arc tube or a special kind of cathode-ray tube. The ultraviolet is focused by means of quartz or fluorite lenses, since glass blocks most ultraviolet. In producing a television image from ultra-



A dark-field photomicrograph of the diatom, *Pinnularia dactylus*, seen at about 1,075 times its actual size.

both photos, 308, 309 bottom, Dicalite Division/Grefco, Inc.—Richard B. Hoover

violet, an ultraviolet converter tube is used. This generates a flow of electrons in response to the ultraviolet image coming from the microscope. The image is then reproduced on the screen.

In the flying-spot ultraviolet microscope, a beam of ultraviolet, generated by a kind of cathode-ray tube, scans the specimen in a definite pattern. The ultraviolet signals obtained from the specimen are reproduced electronically as light images on the screen of another cathode-ray tube. Ultraviolet microscopes are especially useful in showing up fine details in biological cells and tissues.

Other types of optical microscopes. It would be impossible in an article of this size to discuss all the types of optical microscopes. In addition to those we have already described, we might mention a few other types. In *projection microscopes,* the image is projected onto a screen so that a number of persons can view it at one time. The image of the *television microscope* is transferred to a television-camera tube. It can be shown by television to great numbers of observers at a distance from the specimen. The objective and eyepiece of the *inverted microscope* are below the stage and the light is above the stage when light is transmitted through the specimen. The light source is set below the stage when light is to be reflected from an opaque object. The *comparison microscope* is a combination of two microscopes set on different stands one beside the other and connected by a special eyepiece. By studying the two images formed side by side, objects on a microscopic scale can be readily compared.

NONOPTICAL MICROSCOPES

Nonoptical microscopes magnify objects by means of radiation of short wavelengths, such as is provided by X rays, ions, and electrons. With these instruments, much higher magnifications can be obtained than with optical microscopes. This is because magnification depends on the wavelength of the radiation that is used. The shorter the wavelength, the higher the magnification.

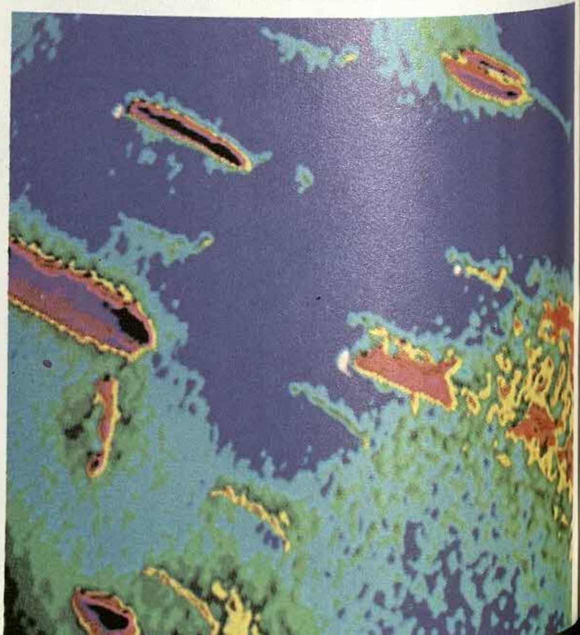
As we pointed out, optical microscopes can bring about a magnification of up to about 2,000 X. The enlarged images provided by nonoptical microscopes may give enlargements of a hundred thousand times or more. Magnifications of more than a million times have been achieved by some of these instruments.

One of the chief problems in the design of a nonoptical instrument is to convert the invisible image produced by the radiation it uses into a visible one. This can be done in several ways: (1) by means of a fluorescent screen that responds directly to the invisible radiation; (2) by providing photographic film sensitive to the invisible radiation; (3) by the use of special cathode-ray and television tubes. A nonoptical instrument, therefore, makes use of at least two forms of radiation (one of which is light).

Another problem in nonoptical microscopy is to focus the invisible radiation. Glass lenses cannot be used because they have no effect upon or may distort this type of radiation. Other means of focusing must be provided. In the case of certain nonoptical microscopes, electrical or magnetic fields are applied, as we shall explain later.

A vacuum must generally be maintained inside a nonoptical scope, because air or other gases may block the paths of the radiation or weaken it. Too intense radiation, however, may damage or destroy the

Color coding of electron micrographs helps researchers analyze what they see. Here, the coloring enhances the visibility of structural defects.

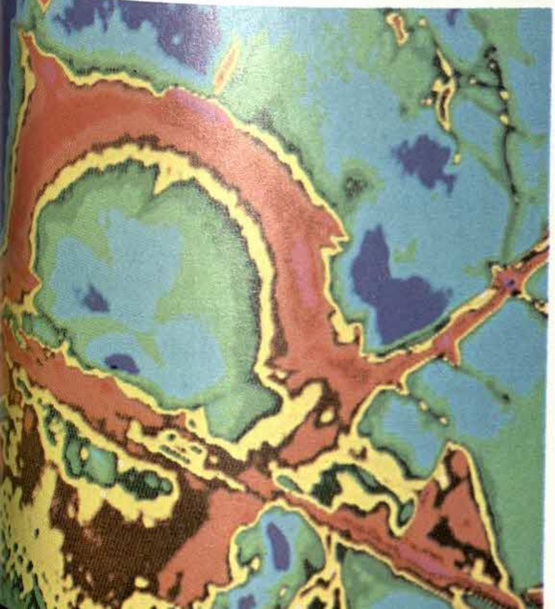


specimen under observation. Hence only objects that can be made to withstand these operating conditions can be examined with such an instrument.

All these factors combine to make most nonoptical instruments complex, bulky, expensive, and difficult to use. This has somewhat limited their application in research. However, recent progress in this field has not only increased the power and resolution of nonoptical instruments but has also made them more flexible and adaptable in the study of a wider range of objects.

X-RAY MICROSCOPES

X-ray devices have been used for many years—among other things, for medical diagnosis and in the study of the crystalline structure of solid matter. X rays are usually generated in a special kind of tube, called an *X-ray tube*. The cathode, or negative electrode is usually a coiled filament of tungsten wire. The target, or positive electrode is made of a heavy metal. When a high-voltage electric current is turned on, the cathode is heated and gives off a stream of fast-moving electrons. As these strike the target, X rays are emitted from the latter. These rays can penetrate even relatively dense materials. When an object is placed in the paths of X rays, some parts of the object may be opaque to the rays. The invisible X-ray image is recorded as a light image directly on a fluorescent screen or on X-ray film. The structure of the object is then revealed as a pattern of light and shadow. The ordinary X-ray film does not present an enlarged image.


Dow Chemical Co.

One of the simplest methods of X-ray microscopy is to place the specimen directly on an X-ray film. After exposure to X rays, an unenlarged image is recorded on the film. The image is then enlarged photographically. This process is known as *contact microradiography*.

A directly magnified X-ray image may be formed on a film or fluorescent screen by moving the specimen some distance away from the film. In this way, an enlarged shadow of the specimen is projected on the screen or film. This method is called *X-ray shadow microscopy*, or *X-ray projection microscopy*. The image may be magnified still more by the photographic enlargement of the film, as in the contact microradiographic method.

The development of an X-ray microscope that magnifies objects by means of the refraction or reflection of X rays has been a difficult job. It has been achieved by the use of concave mirrors of polished metal that reflect and focus the rays at very low angles.

FIELD-EMISSION AND FIELD-ION MICROSCOPES

In the *field-emission microscope*, the specimen is a rounded needle tip mounted in a high-vacuum tube opposite a phosphorescent screen. When a negative high voltage is applied to the tip of the needle, electrons are emitted from it. They strike the phosphorescent screen and produce a highly magnified visible image of the needle-tip surface.

An event more highly magnified image is produced by the *field-ion microscope*. In this, the tube is filled with a small amount of low-pressure gas, usually helium. When a high voltage is applied, the helium atoms that are in contact with the surface of the needle tips will each lose an electron and will become positive helium ions. They will be accelerated toward the phosphorescent screen, where they will provide a visible image. Resolution is so fine and enlargement is so extreme (a million times and more) in the field-ion microscope that individual atoms of metal are made visible.

ELECTRON MICROSCOPES

Electron microscopes have been under development since the early 1930s and a wide variety of types now exist. They are far more powerful than optical microscopes, though the extreme magnification of the field-ion microscope has not been reached. With the electron microscope, magnifications of up to a quarter of a million times have been achieved.

To understand the working of electron microscopes, it would be well to recall a few facts about electrons. They are often considered as minute particles of matter, each carrying a negative charge of electricity. In some respects, however, electrons act like waves. Electron waves have velocity, intensity and a characteristic wavelength; they can be reflected, refracted and scattered. However, there are important differences between light waves and electron waves. Unlike light waves, electron waves are very strongly influenced by electrical and magnetic fields. Moreover, they can be easily scattered or absorbed by thin layers of solid matter or by gases.

An electron beam replaces light radiation in the electron microscope. The beam is focused by "lenses" consisting of either electrical or magnetic fields, which are shaped in such a way as to serve the purpose of lenses. The electric fields are generated by electrodes; the electromagnetic fields, by electromagnets. A high vacuum must be provided so that the electrons forming the beam will not be scattered by air or other gases.

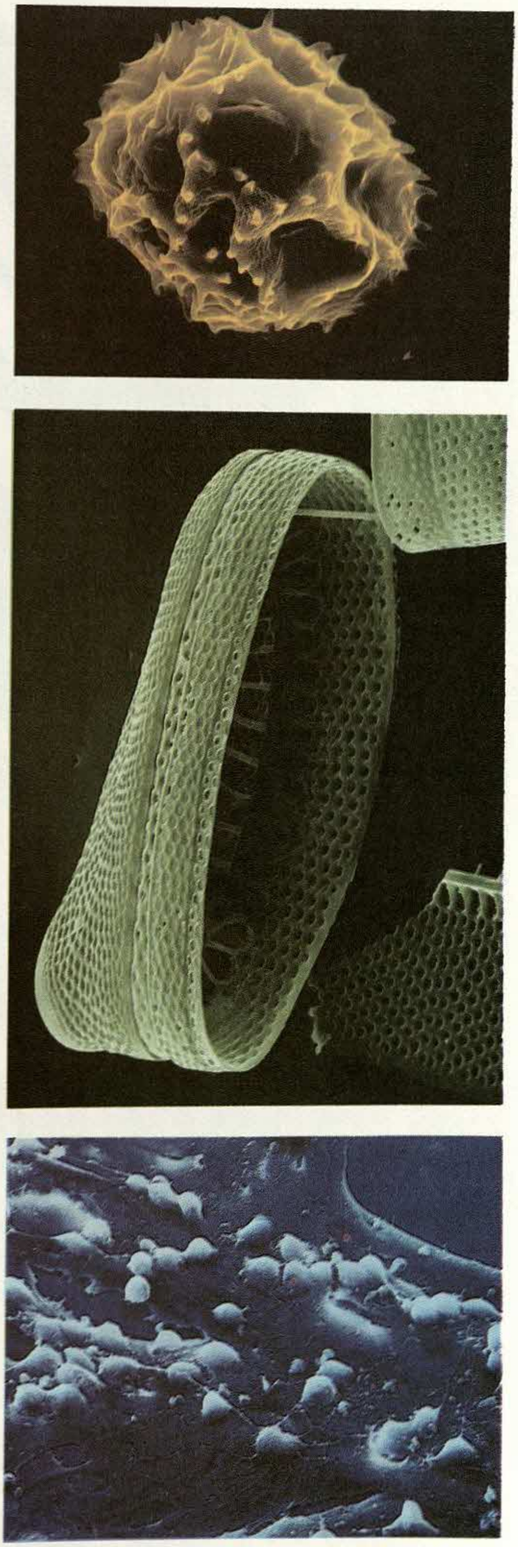
Electron transmission microscopes. All the working parts of the electron microscope are housed in a vertical tube more than one meter in length. At the top of the tube is an electron gun that is used to generate electrons. A tungsten filament in the gun is heated to a very high temperature. It emits electrons, which are then accelerated. The electron beam is concentrated by *condenser coils* before it falls on the specimen, which has been set on a *specimen holder.* The specimen either diffracts (scatters), absorbs, or reflects electrons, depending on the thickness of its different parts. This will bring about contrast in the image.

Philips Electronic Instruments

The electron microscope is vital to medical research. This device has allowed scientists to view the smallest viruses, and to analyze cell structure in detail.

The electrons next pass through an objective coil which acts as a lens, producing an image that represents the first stage of magnification. The image is projected on an intermediate fluorescent screen, which can be viewed through an eyepiece set in the tube. The image can be focused by varying the electric current that generates the magnetic field, until a sharp image is obtained. The electron beam now passes through a *projector coil,* which provides a still higher degree of magnification. The image is then projected on the final fluorescent screen, which is viewed through a window or windows in the tube for final focusing and study. The image can be recorded on a photographic plate set under the screen.

In some models, the vertical tube of the electron microscope is set atop a stand which houses the electrical equipment and

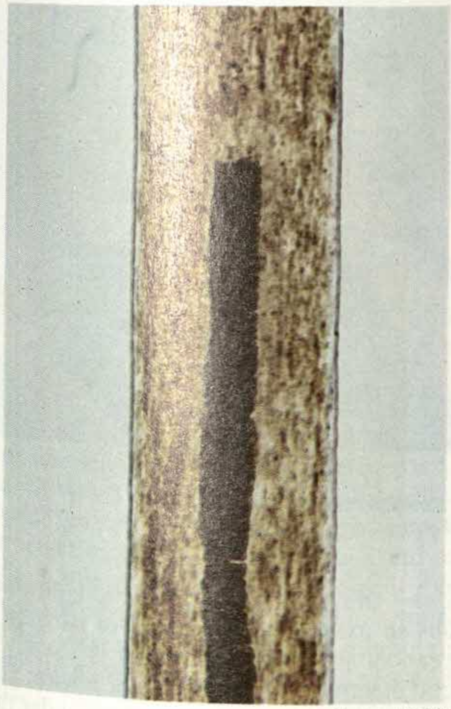


Scanning electron microscopes provide striking images by scanning specimens with a sweeping electronic beam and transmitting the signals to a television-type screen. Right, top: a dandelion pollen grain; middle: a view of diatoms; bottom: a close-up of a cell culture.

L.M. Beidler, The Florida State University

vacuum pumps. In other models, this gear is in a tall cabinet and the vertical tube is set in front of the cabinet.

Specimens to be used in electron microscopes must be very thin and dry. They must usually be specially treated to enhance their visibility to the electron beam. The specimen is set on a thin film stretched over the aperture of the specimen holder. Thicker and higher portions of the specimen are often shaded with opaque deposits of heavy metals. In certain cases, a replica of the surface of the specimen is made. A film-producing liquid is spread over the surface. After drying, the film is stripped off and placed in the specimen holder. Specimens are inserted into the tube through an



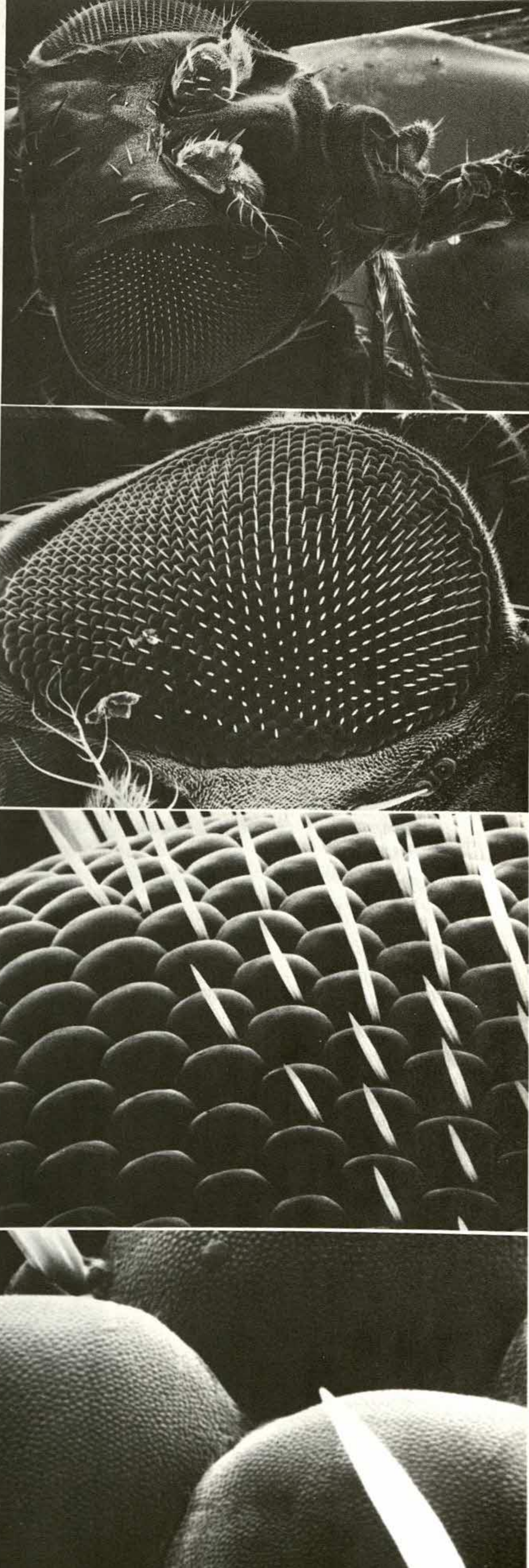
Eastman Kodak Co.

Shaft of a human hair, magnified about 150 times. There is a dark central core, a middle layer that contains melanin, and a flat outer cuticle.

An electron micrograph of the internal structure of a thin sample of lunar rock. The venetian blind-like arrangement seen here is due to plates of pyroxene that formed during cooling after the rock solidified.

airtight locking device in a special chamber. Any air that has entered the tube along with the specimen must be pumped out before the instrument is used.

Electron emission microscopes. Thus far we have been dealing with electronic transmission microscopes. In a different type—the *electron emission microscope*—the specimen is made to emit electrons so as to form an image of itself on a screen or film. The specimen is usually a metal electrode in the shape of a wire, filament or plate. It emits electrons under the influence of electric currents or through bombardment by various forms of radiation or particles. In some instances, a beam of



The scanning electron microscope enables scientists to study objects in three dimensions. It can magnify an object up to 50,000 times. The pictures on this page show the compound eye of a fruit fly at successively higher magnifications. The top frame is magnified 100 times. The bottom frame, magnified 5,600 times, shows the individual facets of the rounded eye.

Photos this page, L. M. Beidler, The Florida State Univ.

electrons is used to stimulate the specimen to give off its own electrons. Electron lenses are not strictly necessary in this device, though they may be used for focusing. The electronic emission microscope is limited to the investigation of metals, which constitute electrodes, or of thin films of matter that have been deposited on these electrodes.

Other Electron Microscopes. There are various other types of electron microscopes. Among these is the *scanning electron microscope*. This device builds up an image of a specimen by scanning it in a definite pattern with a sweeping electronic beam. The signals are transmitted to electronic devices that convert the images into visible enlarged images in a television-type cathode-ray tube. Another type is the *atomic resolution microscope*. Using an electron beam produced by an accelerator, the three-story-high machine produces black-and-white images of atoms deep within solids. Such micrographs show how atoms are mutually bonded, and are useful in studying exotic materials and in developing new ones.

The electron microscope has found applications in many different fields. It has been an extremely effective tool in biological research. It was through the electron microscope, for example, that scientists first learned about the structure of particular viruses known as bacteriophages. The device has provided new insight into the structure of animal and plant cells and bacteria. Large protein and nucleic-acid molecules have been revealed by the instrument. It has served in pathology by pinpointing hitherto unrevealed changes in diseased tissue. It has been a superb research tool in chemistry, physics, and metallurgy. And it has had many applications, too, in the analysis of industrial products and in production control.

HOW TO USE A MICROSCOPE

by Philip Goldstein

So you received a microscope for your birthday. Congratulations! It's a wonderful gift. But what are you going to do with it? Will you treat it as a toy to be played with and then stuck away on a shelf? Or will you consider it an exciting tool that can open your eyes to the hidden wonders of the microscopic world?

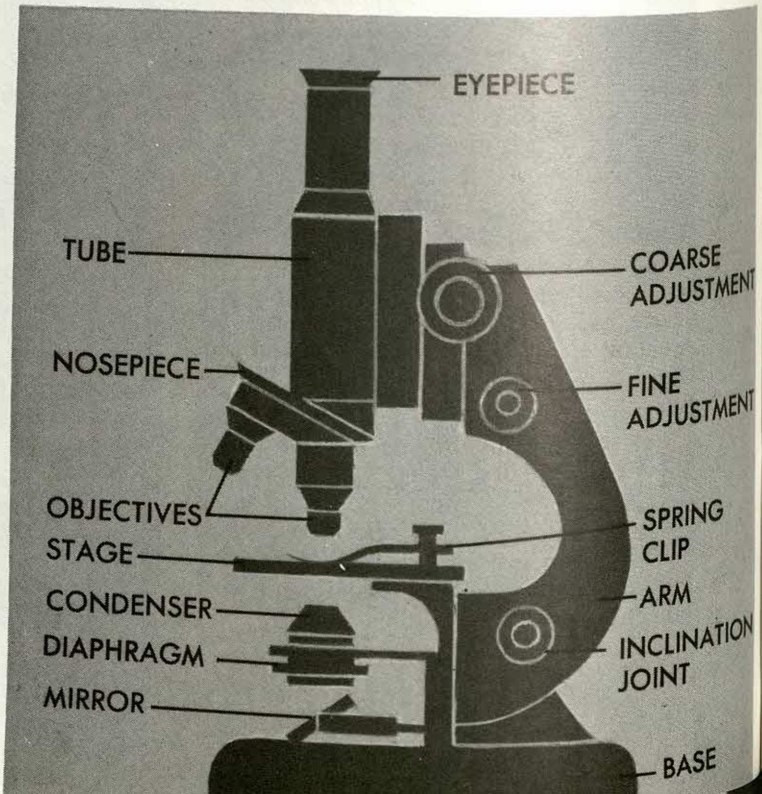
If you hope to use your microscope to the greatest advantage, there is a lot to learn. How does it make things look bigger? What parts does it have? How do they work? What can you look at? How do you make a slide? These and other questions are answered in this article.

PARTS OF THE MICROSCOPE

A microscope is an instrument used to observe small things. When a watchmaker examines the works of a watch with his loupe, he is using a type of microscope. So is the person who uses a reading glass to see the words in his newspaper. And a doctor counting blood cells in a drop of blood is also using a microscope.

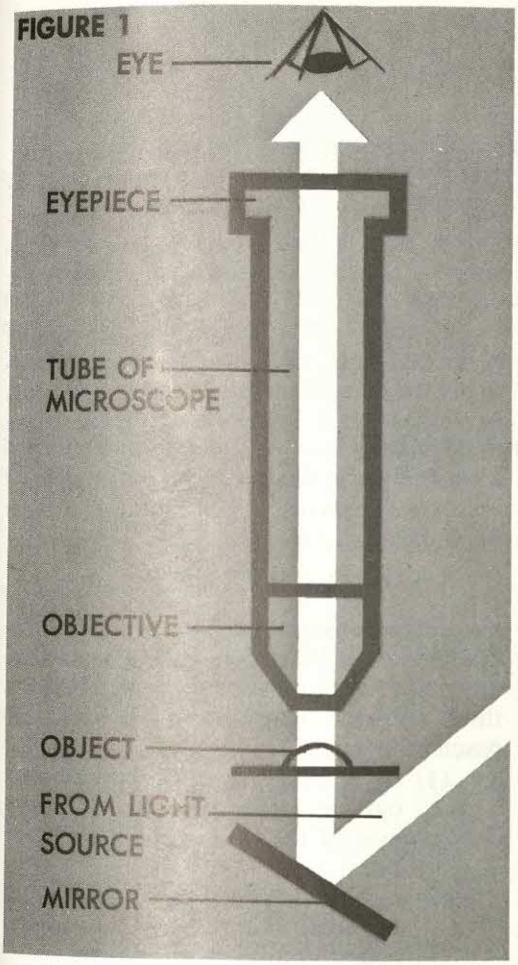
Microscopes make small things appear larger than they really are. This is called *magnification*. Microscopes also enable us to see many details of structure invisible to an unaided eye. This is called *resolution*.

The parts of a microscope that magnify the image and resolve the details are called *lenses*. Microscopes that enlarge in one stage, with a single lens system, are called *simple microscopes*. The watchmaker's loupe and the simple, common reading glass are examples of simple microscopes. Microscopes that enlarge in two successive stages by means of two separate lens systems are called *compound microscopes*. A student-type biological microscope is an example of a compound microscope. Keep



The parts of a compound microscope. To prevent eyestrain, learn to keep both eyes open while looking through your microscope. This will enable you to use the microscope for long periods of time.

FIGURE 1



The path of light through a microscope. Learn to adjust the mirror so that you obtain as much light as possible.

in mind, however, that there are many different types of microscopes.

The parts of a microscope may be grouped into three categories:

(1) optical parts;
(2) parts related to illumination;
(3) mechanical parts.

If you have a microscope in front of you, examine each part as it is described.

Optical parts. These are the lenses that enlarge the object, or magnify, and bring out the details, or resolve. The lenses are carried in a body tube that keeps them the proper distance apart and in a straight line from the object to your eye.

The set of lenses nearest the object is called the *objective*. It provides the first stage of magnification. Its magnifying power is usually engraved on the side of the objective. Your microscope may have two or more objectives of different powers—for example, 10× and 43×. These objectives are carried in a revolving nosepiece that makes it easy to switch from one to the other. As you rotate the nosepiece, a click tells you when the objective locks into place.

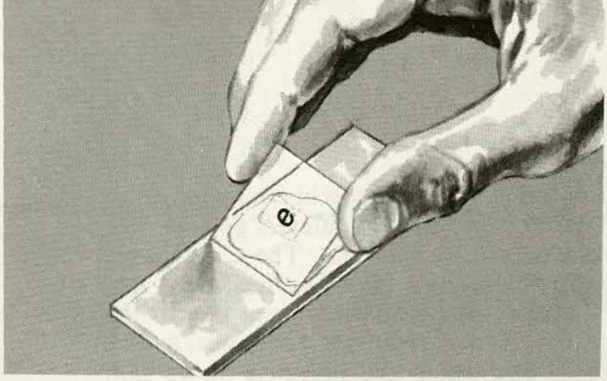
The set of lenses next to which you put your eye is called the *ocular,* or *eyepiece*. It provides the second stage of magnification. Its magnifying power is usually engraved on its upper surface—for example, 10×.

Thus, an object that you examine is first enlarged by the objective and then further enlarged by the eyepiece. The total magnification seen by you equals the product of the two separate magnifications. For example, if you use a 43× objective and a 10× eyepiece, the total magnification is 43 multiplied by 10, or 430 times.

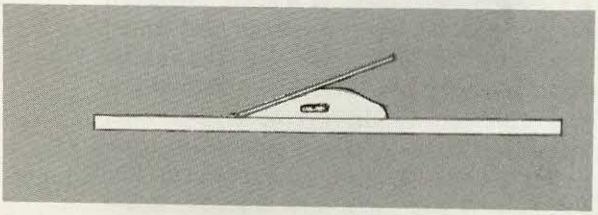
Parts related to illumination. You can only see something through a microscope if light from the object reaches your eye. Some microscopes come equipped with a lamp that sends light rays through the object into the microscope tube. Others have a movable mirror that catches light from a natural or artificial source and reflects it up to your eye. The mirror usually has two sides: a flat side, which is a plane mirror, and a curved side, which is a concave mirror. The flat side is used with natural light sources—sunlight. The concave mirror may be used to concentrate light from artificial sources.

Most microscopes also have a special diaphragm to regulate the cone of light entering the tube. This may be a *disk diaphragm* or an *iris diaphragm*. A disk diaphragm is a metal disk with cutout circles of various sizes. The disk can be rotated to line up any desired circle with the body tube and, thus, with the lenses. The smaller the circle, the smaller the cone of light that enters the microscope. The iris diaphragm is similar to the iris of your eye. It can open wide or be closed down to a pinpoint.

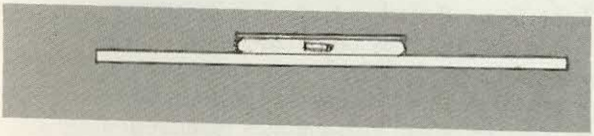
Mechanical parts. These parts make it easy and convenient for you to use your microscope. There is a heavy base, an upright supporting pillar, a curved arm, and a plat-



Holding the cover glass by the edges, rest one end on the slide close to one end of the water drop.

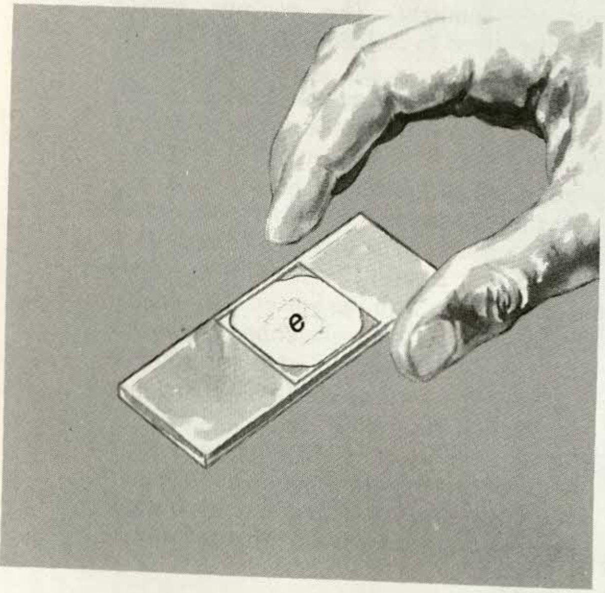


Gradually lower the cover glass until the free end approaches the slide. (Side view.)



Drop the cover glass. It will float on a thin flim of water. (Side view.)

The finished slide. (Top view.)



form called the *stage*. The object to be examined is placed over the hole in the stage and is fastened with *stage clips*. An *inclination joint* allows you to tilt the microscope at a convenient angle for comfortable viewing.

Special *adjustment wheels* operate gears that raise and lower the body tube to focus the microscope. When the object is in clearest view, it is in focus. If the image is not clear, it is out of focus. There are usually two adjustment wheels: a large *coarse-adjustment wheel*, and a smaller *fine-adjustment wheel*.

GOOD LIGHTING–AN ESSENTIAL

In the absence of light your eyes are like those of a blind person. For you to see any object, light must be present. There are three common ways in which light may reach your eyes:

(1) *reflected light:* rays of light from an outside source bounce off the surface of the object and reach your eyes;

(2) *transmitted light:* rays of light from an outside source pass through the object and reach your eyes;

(3) *luminescence:* rays of light produced by the object itself reach your eyes.

In microscope work we usually depend on transmitted light. The mirror directs a beam of light through the object on the microscope stage. The light then passes through the objective and goes up the tube and through the eyepiece to your eye. The resulting image is in various shades of light and dark against a bright, light background. This is known as *bright-field illumination*.

If the specimen on the stage is so thick that light cannot pass through it, your eye sees nothing but darkness through the eyepiece. But the lighting arrangement can be changed so that rays of light bounce off the surface of the specimen and reflect up to your eye. In this manner you get a surface view of the object: a bright, shining image against a black background. This is known as *dark-field illumination*.

We will concentrate on bright-field illumination because this is the kind most com-

USING YOUR MICROSCOPE: A GUIDE TO MINOR PROBLEMS

Problem	Diagnosis	Treatment
The field of vision is black	Light is not reaching your eye	a) Check to see if the objective has clicked into place b) Check to see if the diaphragm is open c) Check to see if the mirror is sending light up into the microscope
The object appears dull and dark	Not enough light is reaching your eye	a) Adjust light to provide more intense illumination b) Check to see if the slide and lenses are smeared c) Perhaps the specimen is too thick to allow enough light to come through
a) The object appears to be in a glare b) Colored rings are present in the field of vision	Illumination is too bright	Cut down on the intensity of the light: a) Use a smaller lamp b) Place a filter in front of the lamp c) Move the lamp further away from the mirror
a) There are dark points and shadows in the field together with bright spots b) The object appears bright on one side and dark on the other side	Illumination is uneven	Adjust the position of the mirror to spread illumination evenly over the entire field
The image shifts as you try to focus	Light entering the microscope is off center	a) Adjust mirror so that the cone of light enters centrally b) Center the condenser if the microscope has one that is adjustable
a) Dark spots in field b) Indistinct, foggy, blurry image that will not focus clearly	Dust or dirt on lenses Lenses smeared with fingerprints, oil or other substance	Locate the dirt and remove it: a) Rotate the eyepiece. If the dirt moves along, it is on the eyepiece b) Move the slide to the right and left. If dirt moves along, it is on the slide. If dirt does not move, it is on the objective
Object cannot be brought into focus under high power without hitting the slide	Working distance of the objective is too small for the distance available	Perhaps the specimen is too thick for study under high power. But first check to see if the slide is wrong side up or if the cover glass is too thick
Fine adjustment wheel will not turn	Wheel has reached the end of its range	Reset the wheel as follows: raise the objective slightly, using the coarse adjustment; turn the fine adjustment wheel in the opposite direction until it reaches the middle of its range. Refocus on the object
Coarse adjustment wheel slips	Wheel is too loose	Tighten wheel as follows: hold right-hand wheel firm while turning left-hand- wheel clockwise
Coarse adjustment wheel hard to turn	Wheel is too tight	Loosen wheel as follows: hold right-hand wheel firm while turning left-hand wheel counterclockwise

monly used. Move the mirror on your microscope. Note how it catches the light from the sky or from a lamp. By turning the mirror you can send the reflected beam wherever you wish. Place the low-power objective (10×) in line with the eyepiece, and see if you can direct the beam of light through the hole in the stage and up the tube of the microscope. Look into the eyepiece. It should be filled by a clear, bright circle of light.

Remove the eyepiece entirely and look again. If the tube is still filled with light, you are ready to go to work. But try one more thing first.

Without changing the light, replace the eyepiece and rotate the nosepiece until the high-power objective clicks into place. How did the change in objectives affect the brightness of the light that reaches your eye? Which objective requires more light to give your eye the same degree of brightness: the low power or the high power?

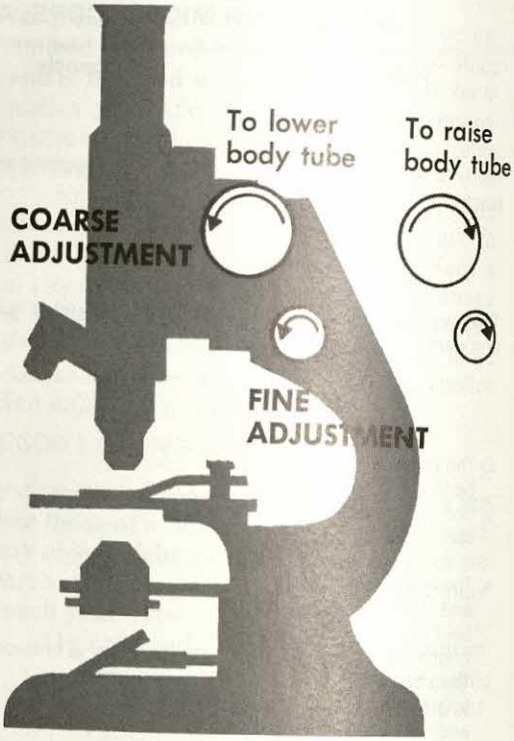
PREPARING A SIMPLE SLIDE

Once you know how to light up the microscope field, you are ready to look at various specimens. But good microscope technique requires a lot of practice. So don't rush into things. Begin slowly and make progress step by step. Here is one suggested approach for learning good microscope technique.

Preparations. We will prepare a simple slide and then use this slide to learn how to manipulate the microscope. First, set up your microscope in a comfortable position. It is very tiring to operate a microscope from a cramped position in which your chest presses against the table. It is just as bad if you have to strain your neck to reach the eyepiece. So choose a chair and table that will be the right height for comfort. Place the microscope in a safe spot on the table—not too close to the edge, and never on a notebook. With the microscope properly placed, adjust the light so the instrument is ready for use.

Your first venture in slide making will be to make a letter $\boxed{e}$ slide. The materials you will need are:

(1) one slide;
(2) one cover glass;
(3) lens paper;
(4) forceps (tweezer);
(5) pipette (medicine dropper);
(6) small scissors;
(7) glass of water;
(8) sheet of newspaper;
(9) pencil and paper.



Practice raising and lowering the body tube. Be careful not to hit the slide or cover glass with the objective.

A slide is a $7^{1}/_{2}$ by $2^{1}/_{2}$-centimeter piece of clear glass. A cover glass is a small square (or circle) of very thin, clear glass. Slides and cover glasses should always be handled by the edges to avoid getting fingerprints on the surfaces. Lens paper is a tissue that is specially prepared for cleaning slides, cover glasses, and microscope lenses. Ordinary facial tissues or a clean, soft cloth are suitable substitutes for lens tissue.

MAKING THE SLIDE

Cut a small square containing a letter $\boxed{e}$ out of the newspaper. Try to locate the smallest $\boxed{e}$ possible that has nothing printed on the reverse side of the paper. Be sure it is a lowercase $\boxed{e}$, and not a capital letter "E."

Place the tiny square of paper in the center of a clean slide. Hold it in place with the forceps while you add a drop of water with the pipette. If the square swings around in the water, line it up again with the tip of the forceps. Now place the cover glass on top of the waterdrop.

In a perfect slide the $\boxed{e}$ will be upright, with the edges of the square of paper running parallel to the edges of the slide. The entire cover glass will rest on a thin, flat film of water. There will be no water on top of the cover glass and no excess water on the slide outside the cover glass. You can soak up excess water with a tiny piece of lens paper. But be careful that you don't remove too much water. Insufficient water under the cover glass makes a poor slide. If any portion of the cover glass is not supported on a film of water, follow the illustrated procedure.

Your slide is now ready for use. But first examine it closely while it is still on the table. Draw the $\boxed{e}$ as it looks to your unaided eye. Be sure that your drawing represents the actual size, shape, color, thickness, and position of the $\boxed{e}$. Is it printed in solid black ink?

Focusing under low power. Place your slide on the microscope stage so that the $\boxed{e}$ is centered over the hole. Be sure the $\boxed{e}$ is in an upright position as you look at it with your unaided eye. Check that the low-power (10×) objective is in place over the slide.

Now put your head down to the side of the microscope until your eyes are at the level of the stage. Grasp the coarse-adjustment wheel and slowly turn it counterclockwise. This lowers the body tube and brings the objective closer to the slide. Stop when the objective is about 0.5 centimeters above the $\boxed{e}$.

Be sure the $\boxed{e}$ is centered under the objective. Then look into the eyepiece. Do you see the $\boxed{e}$? If not, raise the objective very, very slowly by turning the coarse-adjustment wheel toward you. Stop as soon as the $\boxed{e}$ comes into view. Use the fine-adjustment wheel to get the clearest picture.

Draw a new picture of the $\boxed{e}$ as it now appears. Do you observe any differences? Is the $\boxed{e}$ larger? Does it still appear right side up or is it upside down? Has it been reversed from right to left? Does the ink still appear solid black?

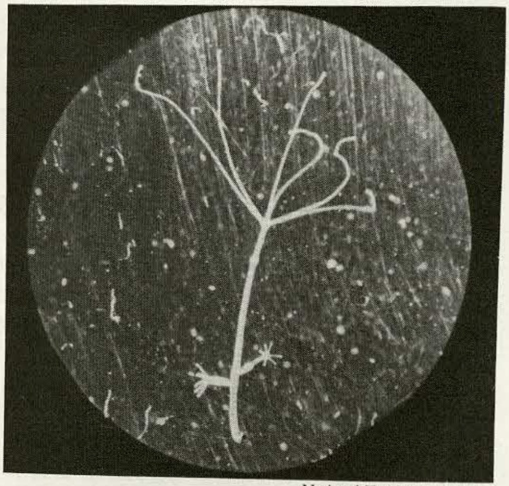
With your eye at the eyepiece, move the slide very slightly to the right. Which way did the image move? Now move the slide slightly to the left. What happens? Which way does the image move if you move the slide away from you? Toward you?

Focusing under high power. Center the $\boxed{e}$ under the low-power objective. With your eye at stage level, rotate the nosepiece until the high-power objective clicks into place. The high-power objective is longer than the low-power objective, so be careful that it does not strike the slide. Now, with your eye at the eyepiece, slowly turn the fine-adjustment wheel toward you until the image clearly appears.

The procedure is modified slightly if there is danger that the high-power objective will hit the slide when you swing it into place. Before rotating the nosepiece, raise the objective just enough to provide clearance. Swing the high-power objective into place. With your eye at stage level, lower the objective until it almost touches the slide. It must be very close—but not quite touching. Now, with your eye at the eyepiece, focus *upward* with the fine adjustment until the image is clear.

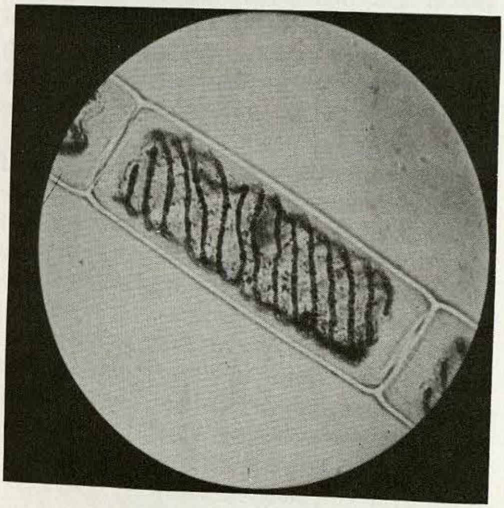
Now you see only a small part of the $\boxed{e}$, but it is more highly magnified than under the low-power objective. Do you see more under low power or high power? This depends on one's definition of "more," doesn't it? Which magnification shows a greater area of the object? Which magnification reveals more detail?

In summary, we can say that the microscope makes the object appear larger and brings out details you cannot see with the unaided eye. It makes the image appear upside down and backward, and reverses the apparent direction of motion. Higher magnifications show a smaller area of the

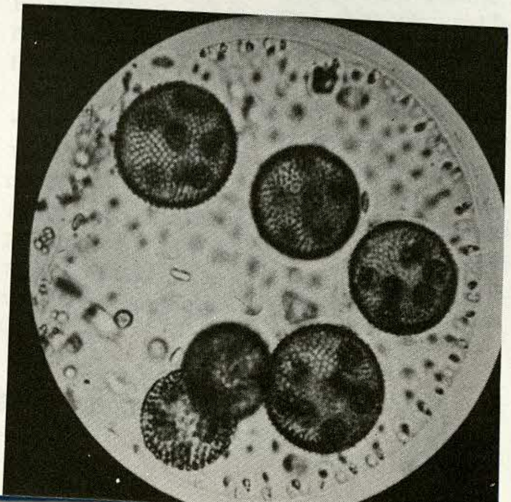


National Teaching Aids, Inc.

This tentacled animal, the hydra, is a common inhabitant of freshwater ponds. Magnification: 25X.



Many different types of algae can be found in a drop of pond water. Here are two common examples: *Spirogyra* (above) and *Volvox* (below). Magnification: 175X and 150X, respectively.



object and require more intense illumination.

A LITTLE CARE GOES A LONG WAY

Your microscope is a precision instrument that should be treated with respect. To carry the microscope, grasp the arm with one hand. Put your other hand under the base for support. Don't swing or bounce your microscope, or jar it as you put it down. Nevery try to lift a microscope by the body tube. You might find part of the microscope crashing ónto the floor if you lift it this way.

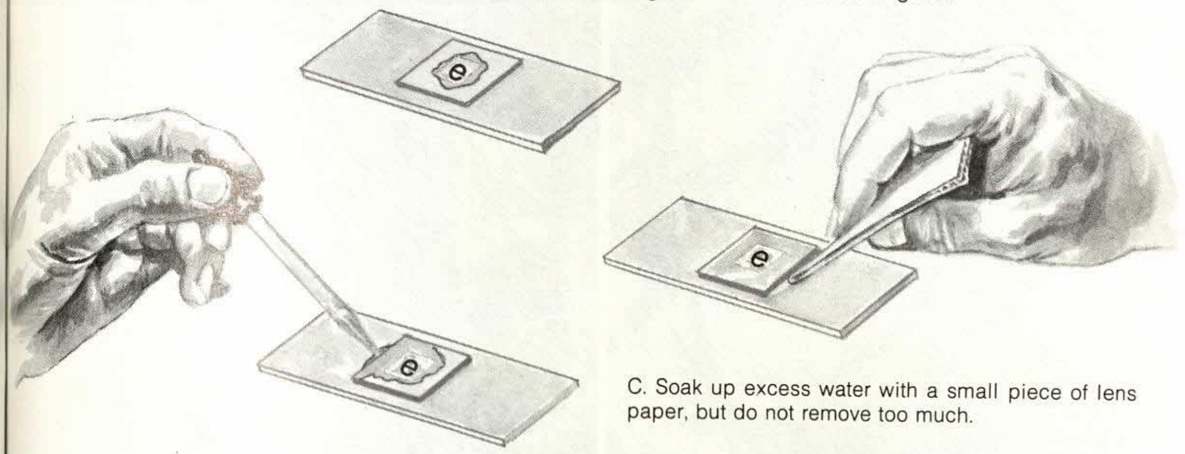
You cannot make good observations with a dirty microscope or dirty slides. Your equipment should be cleaned each time you begin to work. Use a soft cloth to dust the metal parts. Clean the mirror and all the lenses. But be careful: dust is the greatest enemy of lenses. The optical glass of which the lenses are made scratches quite easily. If you rub the lenses in an effort to wipe off the dust, the gritty, abrasive particles will cause scratching. Dust should be blown off the mirror and lenses with a bulb syringe or removed with a camel's hair brush.

Naturally, the less dust that gets on the lenses, the less the chance of scratches. So always keep the eyepiece in the tube to prevent dust from getting on the back of the objective. Keep a plastic dust cover over the microscope when you are not using it, or store it in its case.

Fingerprints smeared on lenses make it impossible to see anything clearly. No matter how careful you are, however, lenses do get smeared. Fingers touch objectives, eyelashes smear oil on eyepieces, and so on.

A dirty lens should be cleaned with a soft cloth, absorbent cotton, or lens paper moistened with soapy water, alcohol, or xylol. Go easy on the solvent: if it gets into the lens system it can loosen the cement that holds the system together.

From time to time you may run into a situation that frustrates you because you don't know what to do about it. Perhaps the chart on page 319 will help you overcome some of these problems.



A. Not enough water under the cover glass.

B. Place the pipette near one edge of the cover glass and then release a drop of water.

C. Soak up excess water with a small piece of lens paper, but do not remove too much.

MORE SLIDES

You have already learned to make a *temporary wet mount* with the letter $\boxed{e}$. The same technique can be applied to many other specimens as long as they are thin enough for light to pass through. Perhaps some of the following suggestions will get you started. Once you begin, new ideas will come faster than you can pursue them.

Pond water. Every freshwater pond supports countless small animals. Some may be visible as tiny white specks scurrying about. Others are invisible to the unaided eye. To explore this fascinating world, you need only put a drop of pond water under the microscope.

Collect samples of pond water from different places. Baby-food jars make excellent containers. In each jar put a little mud or dirt from the bottom in with the water. Add some fragments of the local water plants. Cover the jars and take them home. To examine your treasures, put a drop of the water in the middle of a slide and add a cover glass.

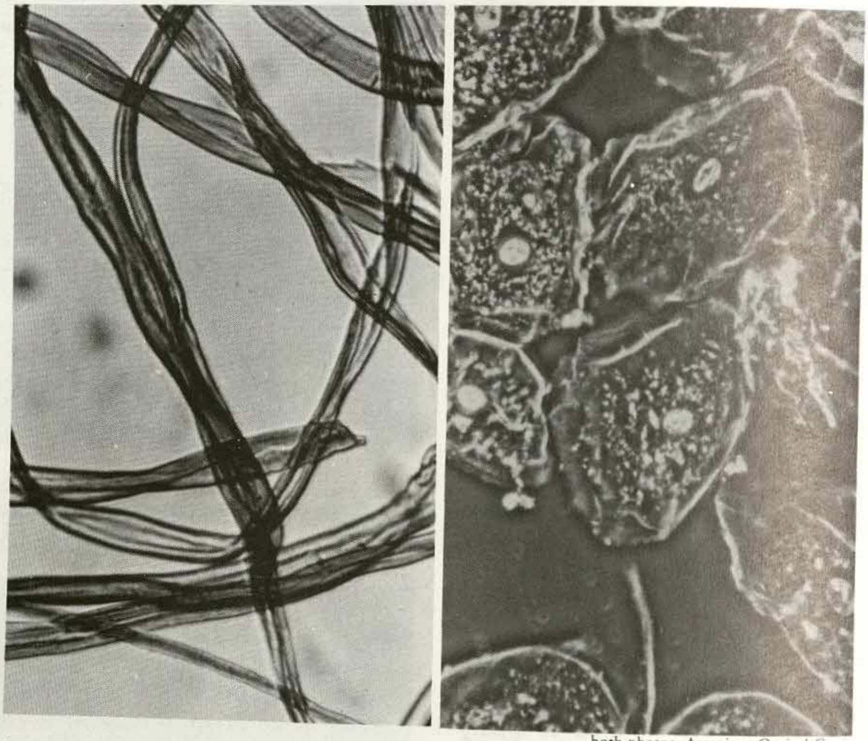
Scan the field under low power to locate the organisms. If you do not find anything at first, do not throw the sample away. The organisms may be very scare. Examine many drops, from different parts of the jar, before you decide there is nothing to see. If you cannot find any living things, let the jar stand undisturbed for several days so that the organisms can reproduce. You may then find your culture teeming with life.

There are many books that you can use to identify the organisms you see. Ask your teacher or librarian to recommend some.

Hay infusion. Fill a large jar about two-thirds full of tap water. Let it stand, uncovered, for three or four days so that air can dissolve in it. Cut some hay or other dried grass into short pieces and drop two handfuls into the water. Cover the jar and allow the culture to incubate about two weeks. If you want to rush things, add a little pond water or aquarium water to the culture.

When the culture is ready, examine several drops taken from different parts of the jar. You will be surprised to see how many different microorganisms appear: bacteria, protozoa, even multicellullar plants and animals. A hay infusion will thrive for months. Just add oxygenated water from time to time to replace that which has evaporated. Keep a record of the organisms you see—you will constantly add to it.

Population change. Life in a culture is always undergoing change. When conditions are good, organisms reproduce rapidly. Such a population explosion, however, soon uses up the available food and pollutes the culture with wastes. The population



both photos, American Optical Corp.

Left: cotton fibers. You can make slides of fibers from a large variety of fabrics: wool, silk, linen, and other natural fibers, and Dacron, polyester, and other synthetic fibers. Right: epithelial cells from the inside lining of a human cheek. This photograph was taken through a phase-contrast microscope.

begins to decline. But what is bad for one organism may be good for another. The same conditions that cause the death of one kind of microorganism may cause a population explosion in another kind. You can witness this rise and fall of populations in any culture. Just keep the culture going for a few months and look at it from time to time.

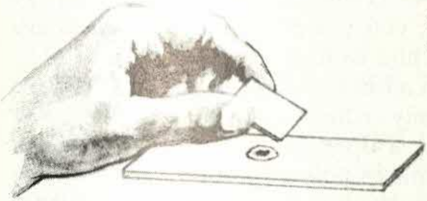
Crystallization. Prepare a very concentrated salt solution in boiling water. Put a drop of this solution on a slide without a cover glass. Look at it under low power and note how clear the liquid is. Observe the slide at thirty-minute intervals. As the water evaporates, beautiful salt crystals appear. Watch them grow.

Try looking at the crystals under darkfield illumination. Cut off all light from below the stage. Position a small, high-intensity lamp so that its light is directed onto the stage from the side. You now see the crystals by reflected light rather than by transmitted light. If you like what you see, try preparing crystals of other substances: sugar, Epsom salts, copper sulfate, saccharin, instant tea, and so on.

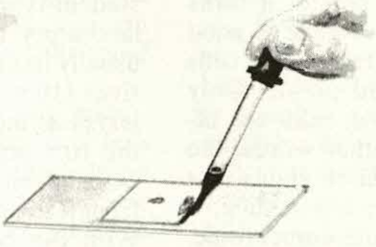
Bread molds and their relatives. Bread kept in a moist, dark place soon becomes moldy. Bread mold looks like dirty gray cotton fluff, with round white and black spots scattered about. These spots contain spores. When ripe (black) they burst, releasing microscopic reproductive cells. Transfer a bit of the mold to a drop of water or mineral oil on a slide. Examine under low power. Then add a cover glass and switch to high power. Extend your study of molds by examining other kinds—those growing on cheese or fruit, for example.

Staining. Some things are difficult to see under a microscope because they have

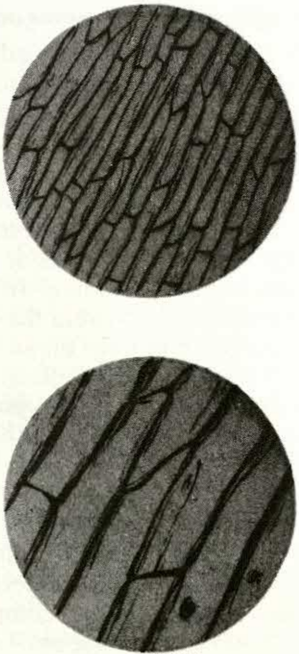
A. Carefully peel off a piece of the thin skin found on the inside of each onion layer



B. Place the onionskin in a drop of water and cover with a cover slip



C. Add a drop of dilute iodine at the edge of the cover slip



D. Examine the onionskin, under low power and then under high power

little or no color. This problem may be solved by staining the object with colored dyes. Different structures in the object will absorb the dye differently: some will stain darkly, others lightly, some not at all. Thus the dye creates visible contrasts that did not exist before.

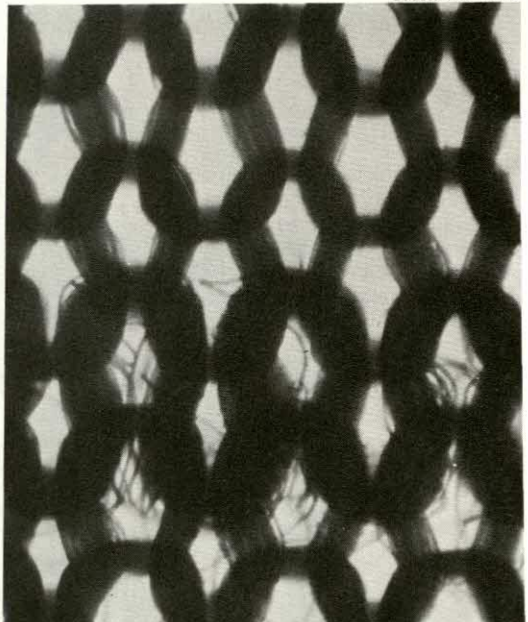
Any colored liquid can act as a stain. Try iodine, merthiolate, mercurochrome, or gentian violet. One or more of these are commonly found in a home medicine chest. A toothpick makes a fine applicator. Dip the toothpick in the stain and swish it about in the liquid on the slide.

For your first stained slide, gently scrape a few cells from the inside lining of your cheek with the blunt end of a toothpick. Smear the scrapings on a slide, add a drop of water, and stain with iodine as described above. Add a cover glass and examine under low and high power. Notice that the cells stain light brown, but the nucleus and certain granules inside the cell appear dark brown.

You can also make a stained slide using a very, very thin fragment from the inside of a potato. Mount this fragment on a slide. Add a drop of water and a cover

Microscopic view of a nylon stocking. Examine several stockings to determine if all stockings are manufactured the same way. It might be interesting to examine other types of fibers.

Bausch and Lomb



glass. Examine under low power. Now run a tiny drop of iodine under the cover glass and watch it approach the edge of the potato. A remarkable change occurs. As soon as the iodine touches the potato, it turns dark blue or purple. If your slide is good enough, you can see that the potato cells themselves have not turned purple. Only the starch grains inside the cells are affected by the iodine. In other words, the iodine makes visible the starch grains that you could not see on an unstained slide.

Iodine, merthiolate, mercurochrome, and gentian violet are poisons that kill the organisms that they stain. That is why they are used as antiseptics. Perhaps the nontoxic food colors from your kitchen will stain living cells without killing them.

Always use a stain very sparingly. Overstaining turns objects into dark blurs in which details are completely invisible.

Other observations. As you can see, there are many things to look at with a microscope. The few we have mentioned can get you started. As you work, many new ideas will present themselves. You will try new things and, as time passes, develop new and better techniques.

WHAT TO BUY

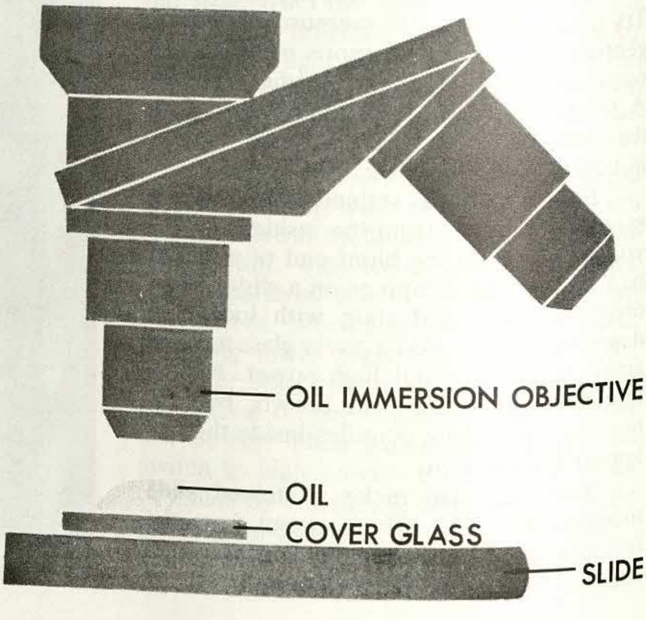
As you progress, you may require a better microscope. Here are a few suggestions on what to look for in buying a microscope.

The first step upward is to replace your student-type biological microscope with a laboratory type. A laboratory microscope usually has a 10× eyepiece and three objectives (10×, 43× *high-dry*, and 97× *oil-immersion*) mounted in a triple nosepiece. If the 10× objective is divisible you gain an extra advantage: in a divisible objective the front lens unscrews, leaving a 4× objective. With the combination of lenses just described, you can get magnifications as low as 40× and as high as 970×.

An oil-immersion lens is designed to be used only when connected to the cover glass by a drop of cedar oil. This type of lens requires powerful illumination. Therefore the microscope should be equipped with a *substage condenser*: a set of lenses below the stage that concentrates the light. There should also be an iris diaphragm and a *substage illuminator* to provide consistent, dependable lighting.

A *mechanical stage* makes it easy to move the slide you are observing. One knob moves the slide forward or backward; another moves it right or left.

Extra eyepieces of different powers or for special purposes are always useful.



An oil-immersion objective is generally needed to examine minute objects such as bacteria. After you place a drop of cedar oil on the cover glass, carefully lower the oil-immersion objective so that it just touches the oil. Focus with the fine-adjustment wheel. After you are finished, use lens paper to wipe the oil off the objective and the cover glass.

Perhaps the most interesting special-purpose eyepiece is the 10×–20× *zoom*. This eyepiece is constructed in such a way that it can change magnification from 10× to 11× to 12× and son on—up to 20×. Thus, if you are using it with a 10× objective, you can get any magnification between 100× and 200×.

The most important parts of a microscope are its lenses. Any defect in a lens can distort the image or break the light up into rainbows of color. A better microscope should be equipped with lenses corrected to eliminate these defects. It should have *achromatic* objectives and eyepieces. These contain lenses that do not break up the light into colors.

Don't be talked into buying a microscope merely because of its high magnifying power. While you do want your microscope to magnify, you also want it to resolve fine structures. To illustrate the importance of resolving power, imagine using two different 10× lenses to examine two tiny black dots of the same size.

The two dots may look exactly alike to the unaided eye. Under lens A they are enlarged, but they still look exactly the same. Lens B, however, tells a different story. It shows the first dot is made of many fine parallel lines. This lens was able to pick out and reveal the fine internal structure of the 2 dots because it has a high resolving power. The resolving power of the first lens was too low to separate the delicate structures.

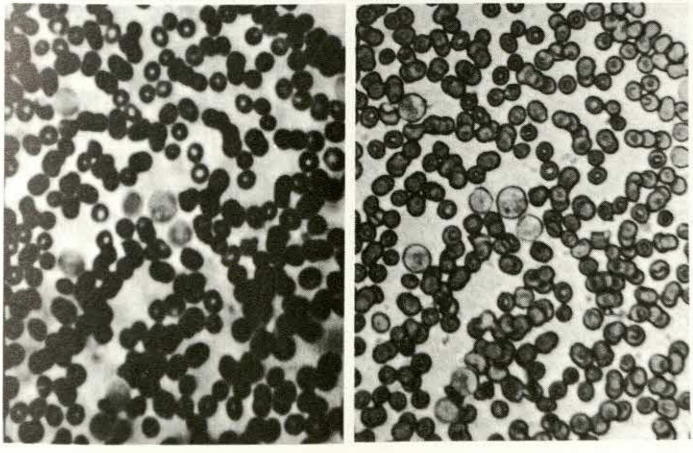
Resolving power depends on the *numerical aperture,* or NA, of a lens. The higher the NA of a lens, the greater its resolving power. Even if your low-power objective only needs an NA of 0.25, you will want a high-power objective of at least 0.65 NA and an oil-immersion objective of 1.25 NA. It is also important that the NA of the substage condenser is about equal to that of your finest lens.

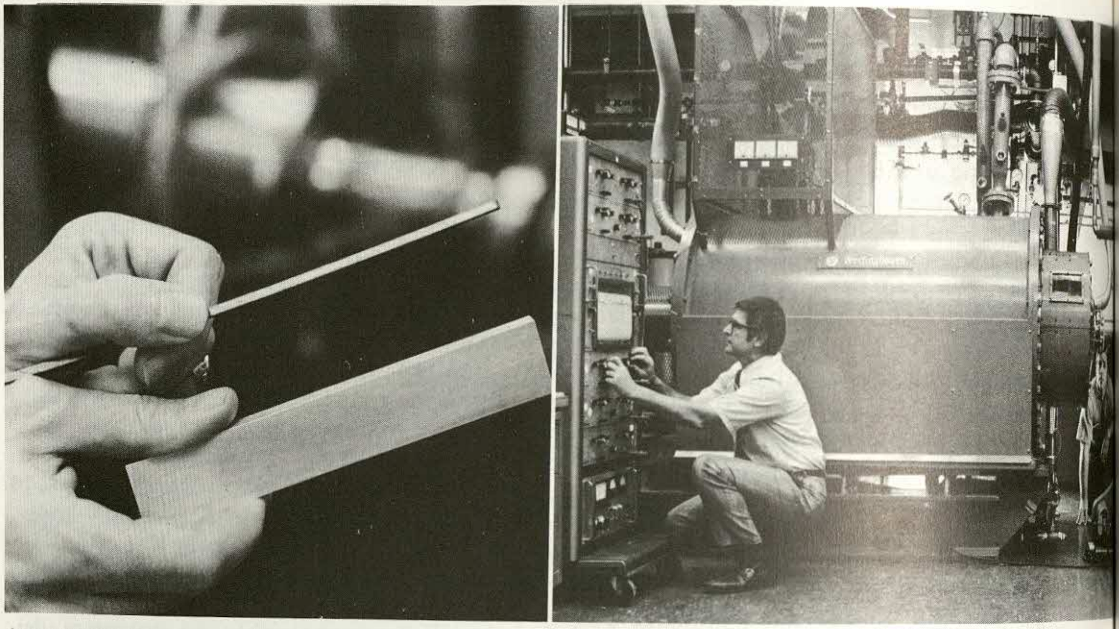
A relatively new approach in microscope work is the use of *phase contrast* to make structures visible. As you now know, with an ordinary microscope it is often necessary to color the specimen with dyes to bring out certain structures. A phase-contrast microscope makes the structures visible without dyes. Instead it depends on the interference of light rays to produce the contrasts needed to make the structures visible. If you are buying a better microscope, you might consider one equipped with phase contrast.

And now, good luck! Whichever microscope you use, there are some wonderful adventures waiting for you.

Top: bone marrow viewed through an optical microscope. Bottom: bone marrow viewed through an ultrasound microscope. The optical microscope gives a sharper image, but dye had to be added to the specimen to produce the image.

Courtesy of Dr. C.F. Quate, W.W. Hansen Laboratories of Physics, Stanford University





both photos, Westinghouse

At extremely low—cryogenic—temperatures, some metals become superconductors of electricity. Left: an ordinary copper bar is compared with a thin wire of superconducting material. The wire can carry the same amount of electricity as the bar. It is used in the small, but powerful, superconducting generator, at right.

CRYOGENICS

by Howard O. McMahon

Cryogenics, a word derived from the Greek (*kryos* means "cold"), is the science of very low temperatures. It had its birth in the latter half of the nineteenth century when, for the first time, researchers learned how to cool things to a temperature lower than has ever existed naturally on earth. It then became possible to reduce certain gases to the liquid state in the laboratory.

EARLY WORK

The ability to create artificially low temperatures was a consequence of understanding the behavior of gases in detail. The early work of the British scientists Davy, Faraday, Boyle, and Lord Kelvin, among others, provided such a basis. It was observed that gases heat up when compressed and cool off when expanded. The entire science of refrigeration, even down to liquid-helium temperatures, is based upon the compression and expansion of gases.

Air was first liquefied in 1885 by the Polish scientists Karol S. Olszewski and Z. von Wroblewski, and ten years later both they and the British scientist Sir James Dewar liquefied hydrogen. Almost twenty more years elapsed before helium, the last of the so-called noble gases, was finally reduced to the liquid state in 1908 by the Dutch physicist Heike Kamerlingh-Onnes. And now the door was opened into a strange new world of experimentation, where all substances except for liquid helium itself are solids that are only a few degrees removed from absolute zero. Absolute zero is equal to $-273.16°$ Celsuis, or 0° Kelvin.

LIQUID HELIUM

It was particularly the researches on the liquefaction of helium that made it possible to obtain the extremely low temperatures with which cryogenicists work.

Engineers have found an electric-insulation material able to withstand over 500,000 volts at ultra-low temperatures. This may be of great importance for future power transmission systems.

General Electric

Helium is the lightest and most inert of all the noble gases. Because of this, the attractive forces between its atoms are almost nonexistent, and consequently it remains gaseous when all other substances have become liquids. The boiling temperature of liquid helium is −268.9° Celcius—just 4.26° Kelvin. If liquid helium is cooled still further—for example, by subjecting it to a vacuum—it does not freeze as all other known liquids do. Instead, at about 2.2° Kelvin, it suddenly transforms into a new kind of liquid which has not counterpart among normal liquids. However, helium is readily solidified by raising the pressure of the liquid.

In early experiments with the strange low-temperature form of helium, the liquid showed no measurable resistance to flow. Therefore, it was said to be in the *superfluid state*. *Superfluidity* shows itself in many astonishing ways. For example, liquid helium flows freely through tiny cracks and pores which are so small that even gases will not penetrate at any measurable rate. It can carry heat 1,000,000 times more effectively than copper and 1,000,000,000 times more effectively than normal liquids. Another remarkable property of liquid helium is its ability to spread out into a microscopically thin film over all solid materials which it touches, and then to flow from one place to another at high speed through the agency of this extremely thin film.

The strange behavior of this liquid can be explained as follows. When helium is at a temperature 2.2° Kelvin, some of its atoms have lost their thermal energy and are already at absolute zero. The remainder of the atoms have at least a minute quantity of energy. They behave normally in the sense that they are able to interact and exchange energy as they collide. However, the atoms that are at absolute zero have no thermal energy to exchange upon collision. Transport properties such as diffusion, heat conduction, and viscosity are therefore abnormal as compared with corresponding behavior of normal liquids.

SUPERCONDUCTIVITY

Low-temperature research with superfluid helium and other substances has led to the discovery of some amazing phenomena in addition to those already mentioned. For a number of metals, at temperatures a few degrees above absolute zero, the electrical resistance disappears abruptly and completely.

This very remarkable phenomenon —known as *superconductivity*—was first observed for mercury at approximately the boiling point of liquid helium by Kamerlingh-Onnes in 1911. It has since been discovered that a large number of metals behave in a similar way at temperatures ranging between 0.5° and 18.0° Kelvin. It is, of course, a matter of some interest to know whether the resistance is exactly zero or only very small. All experiments to date indicate the resistance is truly zero. For example, in one experiment, a current of several hundred amperes was induced in a closed lead ring maintained at liquid-helium temperature and was shown to be still flowing with no measurable diminution after a period of two years.

These dramatic experiments must have raised hopes in early cryogenicists of being able to build extremely powerful electromagnets, transformers, generators, and motors which would have an efficiency of 100 per cent. But such hopes were soon dashed by the observation that if a superconductor is exposed to a high magnetic field, the electrical resistance returns. Since a current in a conductor always generates a magnetic field, this means that superconductors will only carry a limited current in the resistanceless condition.

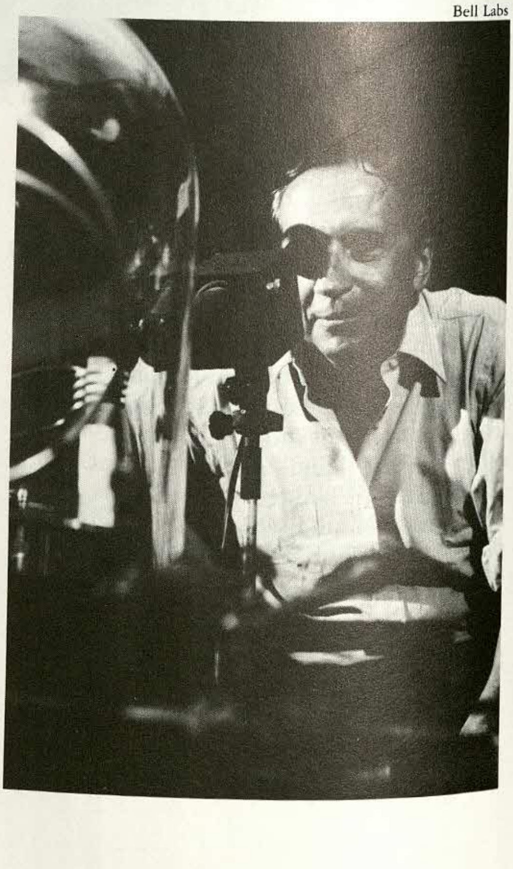
When superconductivity was first discovered, it was thought that the phenomenon could be completely described by the statement that the electrical resistance is zero. Later, however, it was found that this is not a complete description. At the same time that the resistance disappears, any magnetic field which is present is expelled from the body. Hence, a superconductor is not only a perfect electrical conductor, but also a perfect magnetic shield. The fact is that persistent electrical eddy currents occur spontaneously on the surface of the superconducting body. These currents exactly cancel any magnetic field initially present in the interior.

Another way of describing a superconductor is to say that it is perfectly *diamagnetic*. A substance is said to be diamagnetic when magnetic lines of force cannot penetrate it as easily as they could penetrate a vacuum. For this reason it is repelled from a magnet.

Thus, for example, a small bar magnet will hover above the bottom of a shallow lead dish at liquid-helium temperature and

Bernd T. Matthias, a pioneer in the development of many superconducting materials.

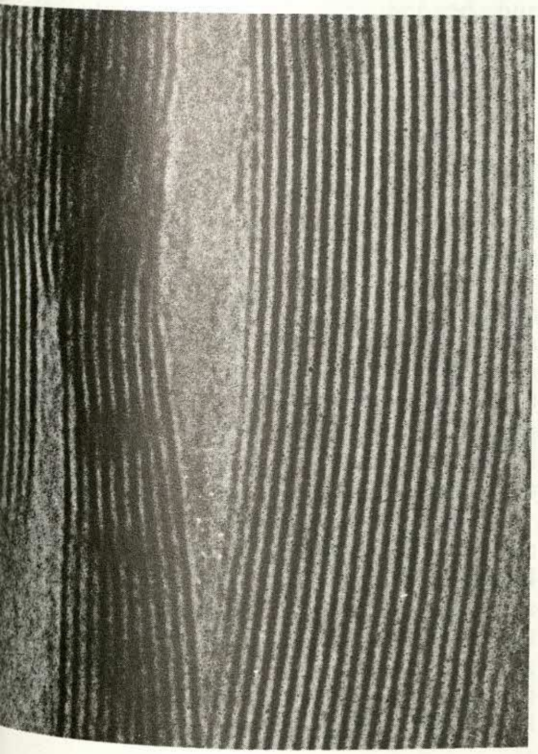
Bell Labs



will skate around in the dish with no measurable friction. A lead ball at such temperatures can be kept above a magnetic field in a completely frictionless condition, becoming a theoretically perfect gyroscope. It will turn over once every twenty-four hours because of the rotation of the earth to which the frictionless support system is attached.

Further research has led to the discovery that certain alloys become superconductive at abnormally high temperatures. For example, Nb_3Sn, a niobium-tin alloy, is superconductive at 18° Kelvin. When cooled to liquid-helium temperature, this alloy retains its superconductivity amazingly well. Powerful electromagnets made of Nb_3Sn will not consume any electric power. They show great promise for use as research tools and for thermonuclear fusion reactors.

Tantalum disulfide is a newly developed superconductor that can be used at relatively high—cryogenically speaking—temperatures. Here is an electron micrograph of extremely thin layers of tantalum disulfide separated by a layer of pyridine.



APPLICATIONS

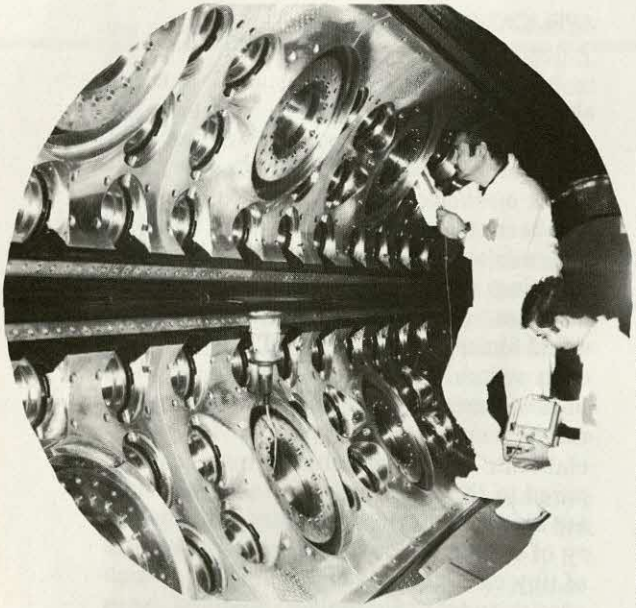
Superconductivity is such a remarkable phenomenon that it would be very strange if there were no practical applications for it—and indeed there are.

In electronics. A great deal of progress has been made in the direction of developing miniaturized, high-speed computing machines using millions of superconductive switches consisting of thin evaporated metal films. The "on" or "off" condition of each switch is determined by the absence or presence of a small electrical current in a neighboring "control" conductor. This elaborate switching network may be compared to the nerve cells of the brain, which are also miniaturized switches. The memory of a superconductive computer consists of tiny circuits, called *current loops,* which persist indefinitely unless modified by a current pulse directed to an appropriate control conductor. Superconductive switches and memory cells for computer applications are called *cryotrons.*

The solid-state maser, a detector and amplifier of microwaves, requires refrigeration to within a few degrees of absolute zero in order to function properly. The purpose of cooling in this case is to reduce the atoms to their lowest energy states in order that the entire population of atoms can be caused to make suitable jumps from one energy level to another in response to radiation of the right frequency. At higher temperatures the atoms have a high degree of thermal excitation and cannot all be ordered into a single state so that they will act in unison.

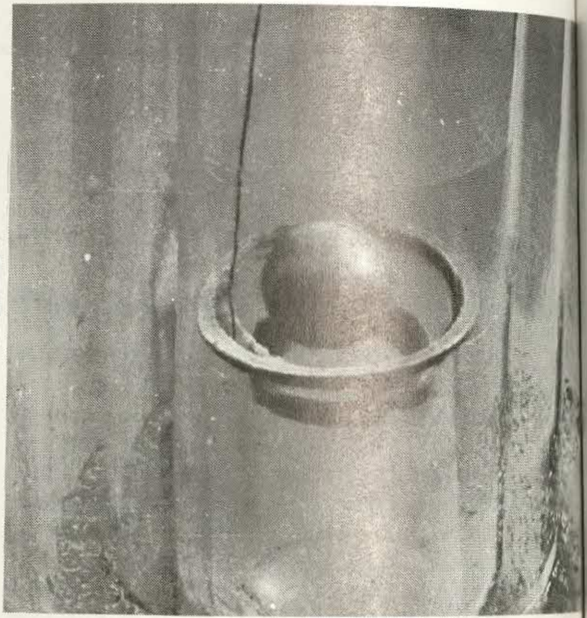
Cooling is important in many other electronic devices in order to suppress the "noise" which is naturally present as a consequence of the chaotic motion caused by higher temperatures.

In laser fusion. Cryogenics has played a vital part in the development of the laser fusion process, which is likely to be a major energy-producing process in the future. Frozen pellets of isotopes of hydrogen—deuterium and tritium—are the fuel for laser fusion. These pellets are raised by lasers to temperatures where fusion oc-



CERN

Bubble chambers are important research tools in high-energy physics. The bubble chamber shown above uses liquid helium, which has been supercooled to 3.5° Kelvin.



Arthur D. Little, Inc.

The superconductive lead sphere shown in the photograph above is supported by a magnetic field in a bath of liquid helium. It can remain floating in this way indefinitely.

curs—that is, where the hydrogen atoms combine, with the release of relatively vast quantities of energy.

In medicine and surgery. Supercold temperatures are also being used in medicine. Low temperatures—around 170° Kelvin—have been used in surgical procedures, including the destruction of tumors, the treatment of certain neurological disorders, and the reattachment of retinas. This branch of medicine is called *cryosurgery*.

In biological research. Research is also underway on methods for deep-freezing tissues and organs for transplant at a later time. The application of temperatures approaching absolute zero to biological systems has been tried, and some lower organisms have survived these extremely low temperatures.

Such *cryobiological* research is giving researchers a good idea of the low temperature extremes that organisms can endure. Such knowledge is important in studies of the possibility of extraterrestrial life, or life outside the earth. Some of the conditions on other planets, here in our solar system and beyond, can be mirrored in the cryogenic laboratory.

THE FUTURE

Other practical uses for extremely low temperatures will undoubtedly be found when we develop a simple, reliable refrigerator that will keep temperatures at the cryogenic range for long periods of time with no more attention than is required by an ordinary household refrigerator. Fortunately, this day is not far away. Certain machines, already in operation, maintain a temperature of 4° Kelvin for continuous periods of approximately one month, and are no larger than a window air-conditiong unit.

But what about lower temperatures, and when does it become impossible to cool further? Already researchers have achieved a low temperature of within twenty millionths of a degree of absolute zero. There is no end to the possibilities for further cooling, even though it may never be possible actually to reach absolute zero.

HOLOGRAPHY

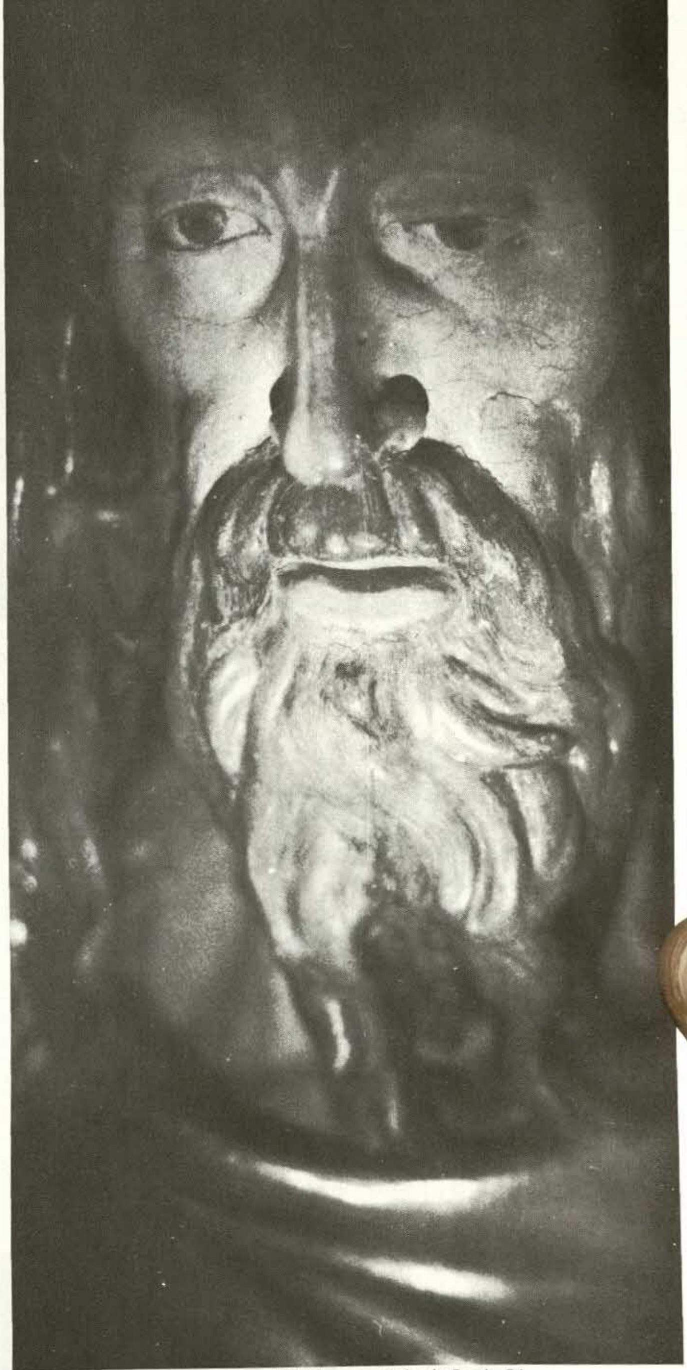
An exciting development in optics is the technique known as *holography*. The name comes from two Greek roots meaning "a complete record," and it is very appropriate. Holography not only records the image of a given object in three dimensions, but the image is also in full color and it is extraordinarily faithful to the original. Basically, holography is a form of photography, in that it produces a permanent record of an object on a photographic plate. However, it differs in important respects from conventional photography.

To understand what holography is, it is necessary to think of light as a succession of waves, moving through space at the speed of about 300,000 kilometers per second. Ordinary white light is made up of different frequencies, the frequencies corresponding to different colors. The waves of different frequencies are not in phase (in step, we might say), and they tend to interfere with one another in random fashion.

HOW IT IS DONE

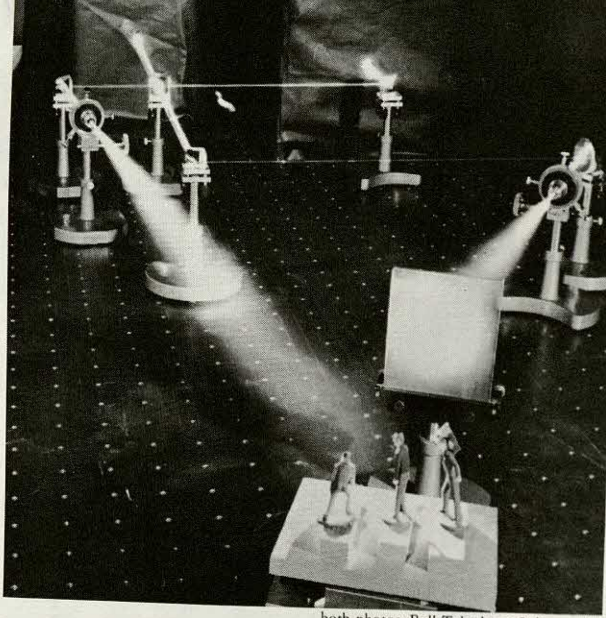
In holography, the interference between waves is controlled and utilized in such a way as to record a permanent image of a given object. In the apparatus used most often today, the light that records the object is provided by a laser beam. The light of a laser beam is *monochromatic*—that is, it is made up of light waves falling within a very narrow range of frequencies and moving in step with one another. The beam of light produced in this way is said to be *coherent*. It is used in holography not to do away with interference but to control it.

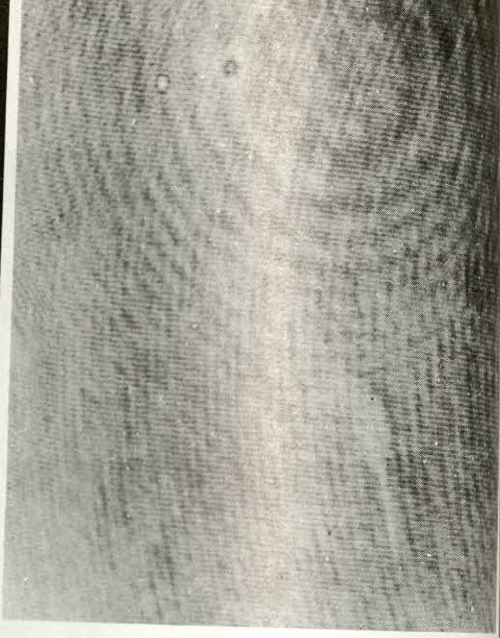
A photographic plate, generally consisting of a glass slide coated with a photographic emulsion, is used. The laser beam does not pass through a lens before striking the photographic plate. It is split into two parts. Beam No. 1 is directed at the object whose image is to be recorded and is then reflected from the object to the photographic plate. Beam No. 2, called the *reference beam*, is focused directly on the plate. As beam No. 1 is reflected from the object to the plate, it gets out of step with the reference beam. Changes in intensity also take place. When the two beams meet in the emulsion of the photographic plate,



TRW Systems, Redondo Beach, CA

Photo of a reconstruction of the hologram of Donatello's St. John the Baptist. Holograms revealed invisible cracks in the statue.





both photos, Bell Telephone Laboratories

Left: making a hologram of the objects in the foreground. Right: the surface of the hologram. It contains the information required to reconstruct a three-dimensional image as one shines a laser or intense white light on the hologram.

they interfere with one another. The interference effects are recorded in the silver particles of the emulsion as a definite pattern of spacing and density. This record is called a *hologram*. It corresponds to the negative in conventional photography, but presents no recognizable image.

VIEWING THE HOLOGRAM

Suppose now that the image stored in the emulsion is exposed to a *read-out beam*—that is, a laser beam of the same frequency as the one that had recorded the image. A startling thing happens. To a viewer, the original object appears to float in space behind the photographic plate. Every detail of the original is reproduced with startling realism. Furthermore, as the viewer moves his head, he can make out details that were originally blocked out by objects in the foreground. The background comes more clearly into focus as the foreground begins to blur. All this has been presented to the viewer as a visible image. A photographic print can be made of the hologram, but the print is in two dimensions. Also, any portion of the hologram can generate the entire image.

THREE DIMENSIONS

The first hologram to give three-dimensional images was developed in 1962 by Emmet Leith and Juris Upatnieks, two scientists then at the University of Michigan. This development was the culmination of many years of research. As a matter of fact, two-dimensional images had been produced by light interference patterns as early as 1891 by Gabriel Lippmann, a French photographer. He received the Nobel Prize in physics in 1908 for this achievement. The idea of a three-dimensional image to be produced by interference was proposed by Denis Gabor at the Imperial College of Science and Technology at London in 1947. Gabor tried to utilize the wave pattern of electrons in forming electron interference patterns. But the beam of electrons employed by Gabor did not have the necessary coherence. It was not until the laser became available that the first three-dimensional image was produced.

Holograms have been both produced and viewed by means of ordinary light. An extremely complicated type of apparatus is required for this procedure and the images produced thus far have been disappointing. They are dim and the color values are distorted.

A beginning has been made in producing an animated hologram—a very primitive sort of three-dimensional movie in full color. In this development, several images are produced on a single photographic plate

both photos, McDonnell Douglas Electronics Co.

Left: one of the world's largest hologram reconstructions—an iguana in a tropical jungle. Right: for comparison, part of the original scene used to construct the hologram.

by rotating the plate slightly for each image. The different images are then viewed in rapid succession as the plate is rotated in a beam of ordinary light.

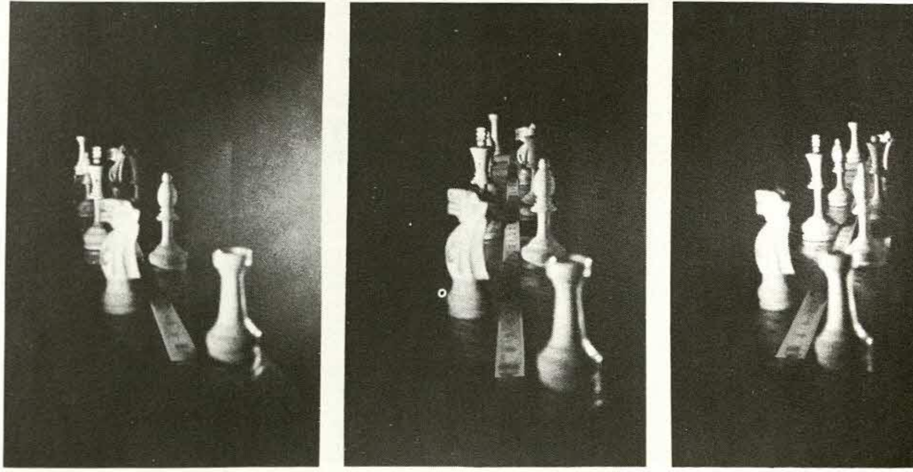
USES

Three-dimensional holography is still under development, but already it has had various applications and many others have been suggested. It has been successfully applied in *interferometry,* which is concerned with the analysis of various properties of liquids, solids, or gases by means of interference phenomena. When holography is used in interferometry, measurements can be made that would be quite impossible by any other method. The technique of holography combined with interferometry can be applied to the analysis of explosions, erosion, plasmas, and stresses in materials.

Since a hologram can be produced in less than 1/1,000,000 of a second in a laser beam, it can be used to study various effects that take place too rapidly to be recorded by any other method of observation. Furthermore, the holographic image can be reconstructed at will, thus enabling a researcher to examine the image at his leisure. Holograms can also be recorded through a microscope.

There are various intriguing possibilities for the future use of holography. It may provide computer memories in which information is stored in the form of light patterns. It may make possible three-dimensional paintings that may represent an entirely new art form. It may provide thrillingly realistic three-dimensional movies and perhaps even television pictures in the home. As we pointed out, animated holograms have already been produced, though on a very limited scale. Will we be able some day to watch movies or television spectacles providing the illusion of motion and life in a way that has never yet been achieved?

Bell Telephone Laboratories



Photographs of a hologram reconstruction. The scene changes as it is viewed from different angles.

Courtesy Laser Images, Inc.

LASERS

Two examples of the use of lasers for entertainment. Left: patterns of color and swirling shapes explode at a Laserium show. Right: lasers at Studio 54 in New York City are fun, but could be dangerous.

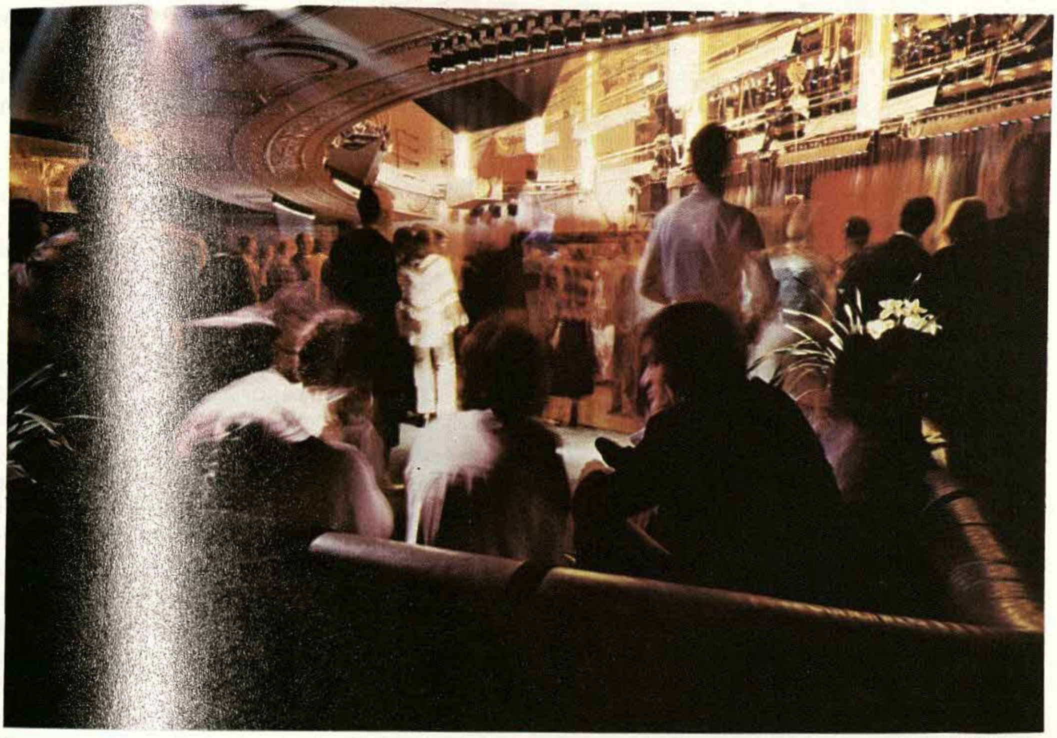
The specifications for the craft's guidance system had been set down and approved. Now they were in the hands of a technician. As she studied the diagrams, the technician noted that the wires for some of the circuits would have to be exceedingly thin. A new die was needed to draw out wire that fine.

She selected a diamond from the ones in front of her, and placed it on a stand. She then took her place behind the laser and made the necessary alignments. A final check, then she hit the switch. A few moments later, the hardest known substance had a hole through its middle. The die was ready. A prophesy for future technology? Not really. Lasers are used every day in many industrial applications.

THE FOUNDATION

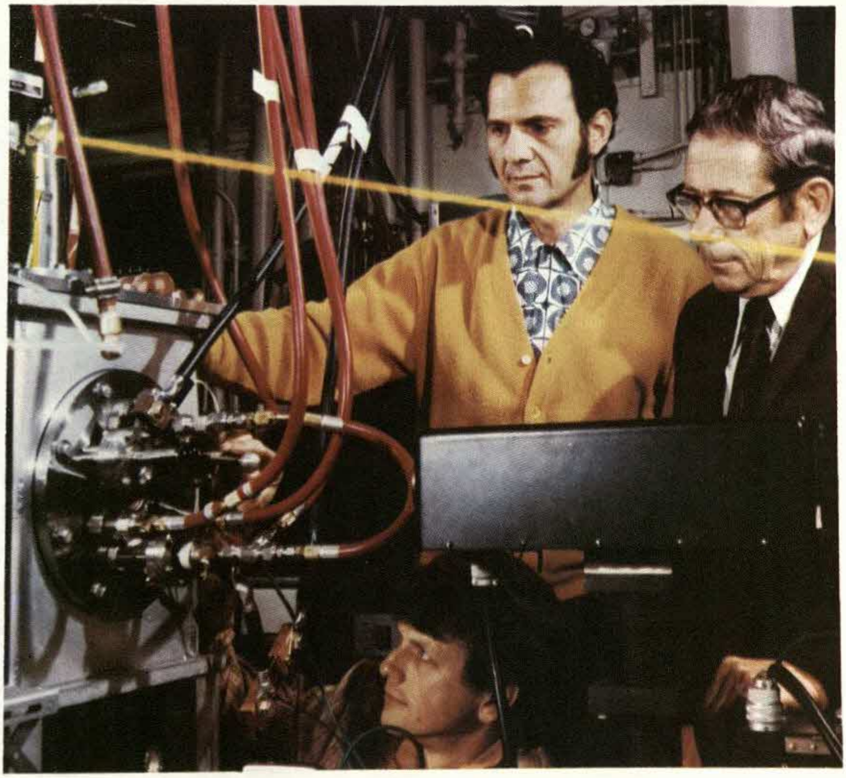
Laser is not really a word. It is an acronym from *L*ight *A*mplification by *S*timulated *E*mission of *R*adiation. The laser has been around since 1960, but the idea of the laser has been around since 1917. In that year, Albert Einstein proposed the mechanism of *stimulated emission*—the principle of the laser's action.

Stimulated emission is a variation of *spontaneous emission,* a process that occurs in atoms. When electrons occupy the lowest energy levels available to them in the atom, the atom is said to be in its *ground,* or unexcited, *state*. If energy is applied to the system, some electrons may be knocked into higher energy states. The atom is now in an excited state. The atom is not in a stable configuration at this point. As the electron drops back into ground state, a photon is released. A photon is a tiny particle of light. This photon could then interact with another excited atom, causing that atom to de-excite itself by releasing yet another photon. This photon would be identical in frequency to the triggering photon. The triggering photon is also unchanged by the collision and keeps traveling. As de-excitation occurs, photons are released in a random fashion. That is, light is emitted in all directions.



Adam Scull/Black Star

Lawrence Livermore Laboratory



In this experimental chamber, a laser beam is used to excite particles of uranium, which is used as a fuel in nuclear reactors.

Stimulated emission is like spontaneous emission, but stimulated emission can cause an amplification, or increase, in the number of photons traveling in a particular direction. The direction can be established by the use of mirrors.

For a noticeable increase of light to occur, there must be more atoms in an excited state than in the ground state. This condition is called a *population inversion.* It is not a normal condition; under normal conditions, more atoms are in the ground state than an excited state.

LASING ACTION

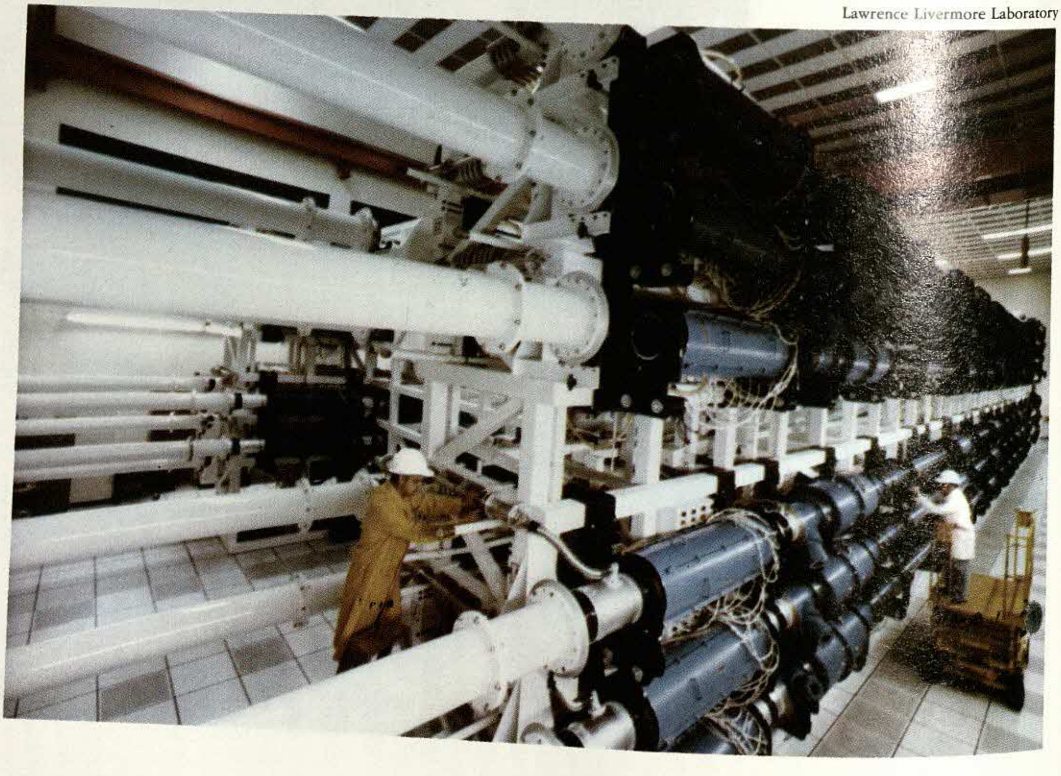
There are prerequisites for *lasing action,* or the action of a laser. You must have three things: 1) a suitable *lasing medium;* 2) an energy source, or *pump;* and 3) an *optical* cavity, which controls the direction of the laser beam.

Lasing mediums. There are three kinds of lasing mediums: solid-state, liquid, and gas. *Solid-state lasers* contain lasing material in a solid matrix. An example of this type is the ruby laser. The ruby is made by introducing a precise amount of chromium into crystalline aluminum oxide. The light that is produced by this laser is deep red in color.

Gas lasers are gas in a glass tube. There are several gas lasers in use. They are the He-Ne, or helium-neon, laser, which has a wavelength in the red part of the spectrum; CO_2, or carbon dioxide, laser, which has a wavelength in the infrared; Ar, or argon, laser with a blue color; Kr, or krypton, laser with a green color; and a H_2O, or water, vapor laser that operates in the infrared.

Liquid lasers use complex organic dyes as their lasting medium. These lasers are very tunable. That is, you can select your dye to give the desired wavelength for the work being done.

Pumps. In order to invert a population of atoms—to make more atoms excited—it is necessary to put energy into the system. Pumps put this energy into the system. *Optical pumps* provide the energy for solid-state and liquid lasers. These pumps are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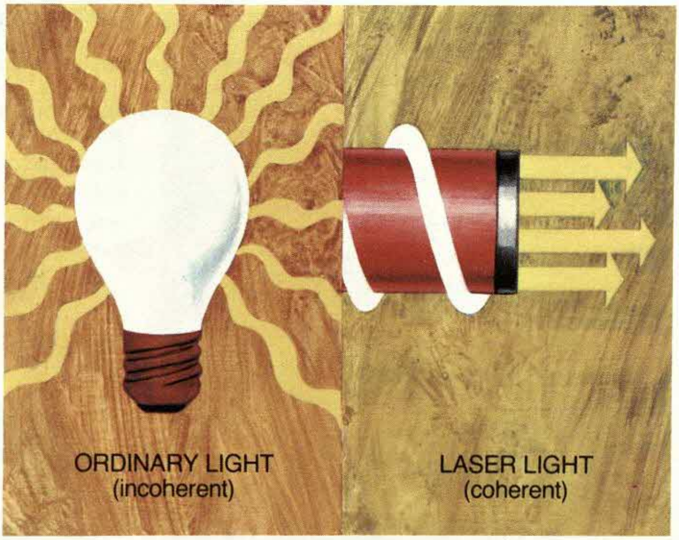


Ordinary, or incoherent, light is an example of the spontaneous emission of photons (tiny particles of light) in all directions. Stimulated emission (right) occurs in laser light, which is coherent light—a concentrated number of photons traveling in the same direction.

just bright light that is focused on the lasing medium. *Electron conversion pumps* are used for gas lasers. These pumps are nothing but an electric discharge sent through a gas tube.

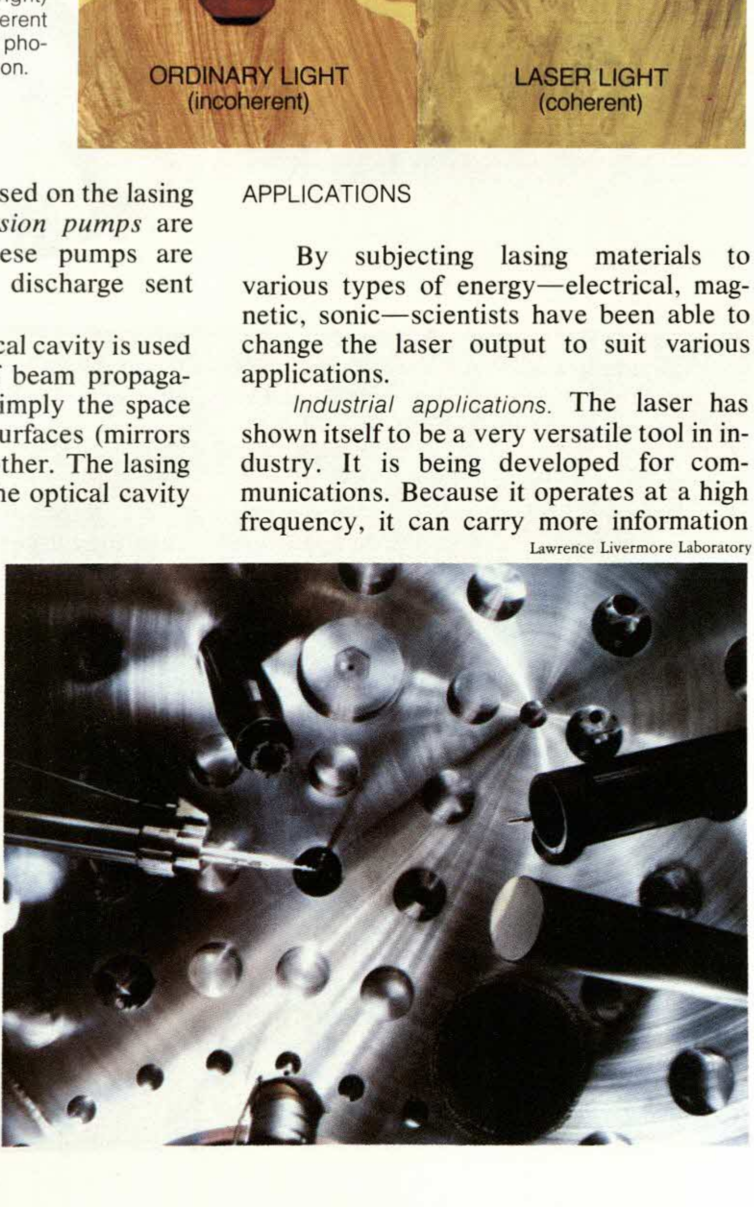
Optical cavity. The optical cavity is used to control the direction of beam propagation. The cavity itself is simply the space formed by two reflective surfaces (mirrors and the like) facing each other. The lasing material is placed within the optical cavity of the laser.

APPLICATIONS

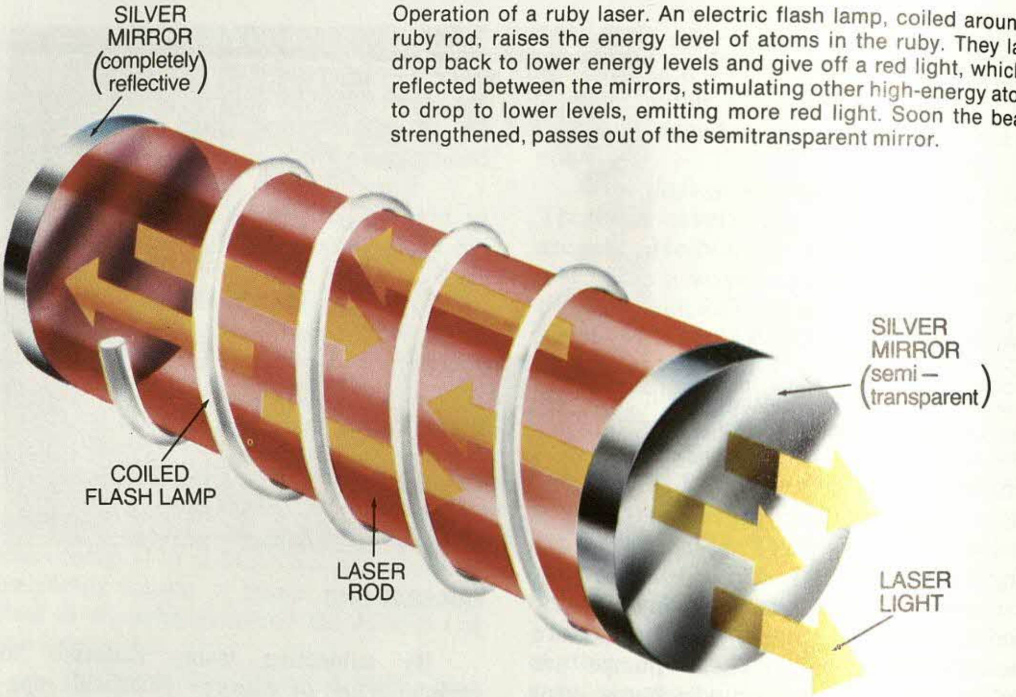
By subjecting lasing materials to various types of energy—electrical, magnetic, sonic—scientists have been able to change the laser output to suit various applications.

Industrial applications. The laser has shown itself to be a very versatile tool in industry. It is being developed for communications. Because it operates at a high frequency, it can carry more information

Lawrence Livermore Laboratory



Two views of the world's most powerful laser system, located at the University of California. Left: six laser amplifier chains direct 30 trillion watts of optical power toward a tiny target located in a target chamber. Right: the target, containing nuclear fuel, is mounted on a needle-like positioner in the center of the chamber.


SILVER MIRROR (completely reflective)
COILED FLASH LAMP
LASER ROD
SILVER MIRROR (semi-transparent)
LASER LIGHT

Operation of a ruby laser. An electric flash lamp, coiled around a ruby rod, raises the energy level of atoms in the ruby. They later drop back to lower energy levels and give off a red light, which is reflected between the mirrors, stimulating other high-energy atoms to drop to lower levels, emitting more red light. Soon the beam, strengthened, passes out of the semitransparent mirror.

than conventional wires. A laser can carry several hundred thousand telephone calls or thousands of television programs at the same time. Effective transmission of laser signals over long distances using fiber optics has already been developed.

Tracking and ranging systems using lasers have been developed. The operation of these systems is similar to that of radar, but light signals are used in place of radio signals. A beam of light is directed at an object. The time it takes for the light to hit the target, bounce off, and return can be used to determine the distance to the object. In seismology the laser can be used to detect small movements of the earth and thus possibly help in earthquake prediction.

The laser is also used with industrial machinery. It can help in aligning heavy construction equipment and, with a device called an interferometer, can control the operations of industrial machinery.

At the beginning of this article, the cutting power of the laser was briefly mentioned. Lasers are used in industry for many cutting and welding operations—especially where small components are involved. Laser beams are used to weld wires on microcircuits, and they can be used to repair damaged wires that are located inside a glass tube.

Lasers are also used in high-speed printing. Their use in three-dimensional photography is discussed in the article "Holography." Laser use in digital sound recording is covered in "Stereophonic Systems," and in video recording in "Video Cassettes and Videodiscs." An increasingly important use in experimental nuclear fusion devices is discussed in the article "Fusion and Energy" in Volume 2.

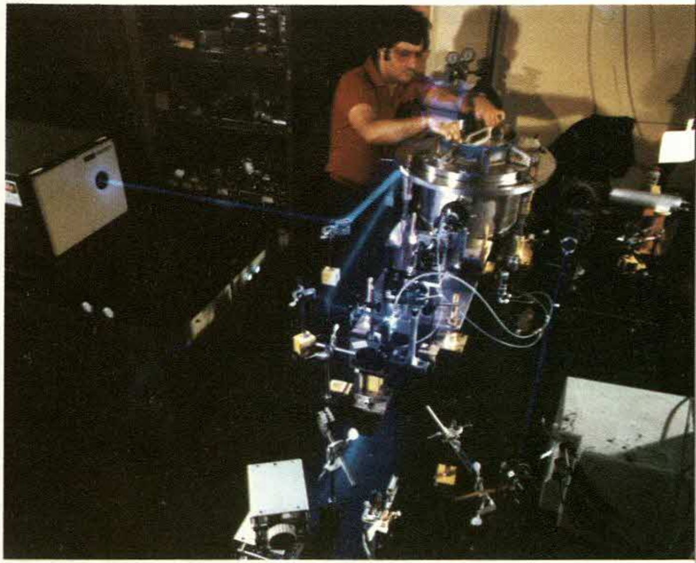
Biological Applications. The use of the laser in biological research and medicine is expanding. Lasers have been used in various surgical operations. In ophthalmic surgery, laser use has been very successful.

The retina of the eye is subject to detachment due to various illnesses and trauma. The laser can be used to spot-weld the detached retina back on to the choroid at the back of the eye.

Cosmetic surgery has also adopted the laser as a tool. An example of this use of lasers is their application in the treatment of angiomas. Angiomas, or port-wine stains, are a proliferation of blood and lymph vessels lying very near the surface of the skin. Laser treatment of these spots causes them to lighten as they heal.

Lasers have been used to treat skin cancer on an experimental basis. The laser beam can be pinpointed on cancer cells and destroy the cells. There are some problems with this treatment, however,. For one thing, the laser impact can push some live cancer cells deeper into the body, thereby spreading the cancer.

There are also possibilities for the utilization of the laser in neurosurgery and dentistry in the future.

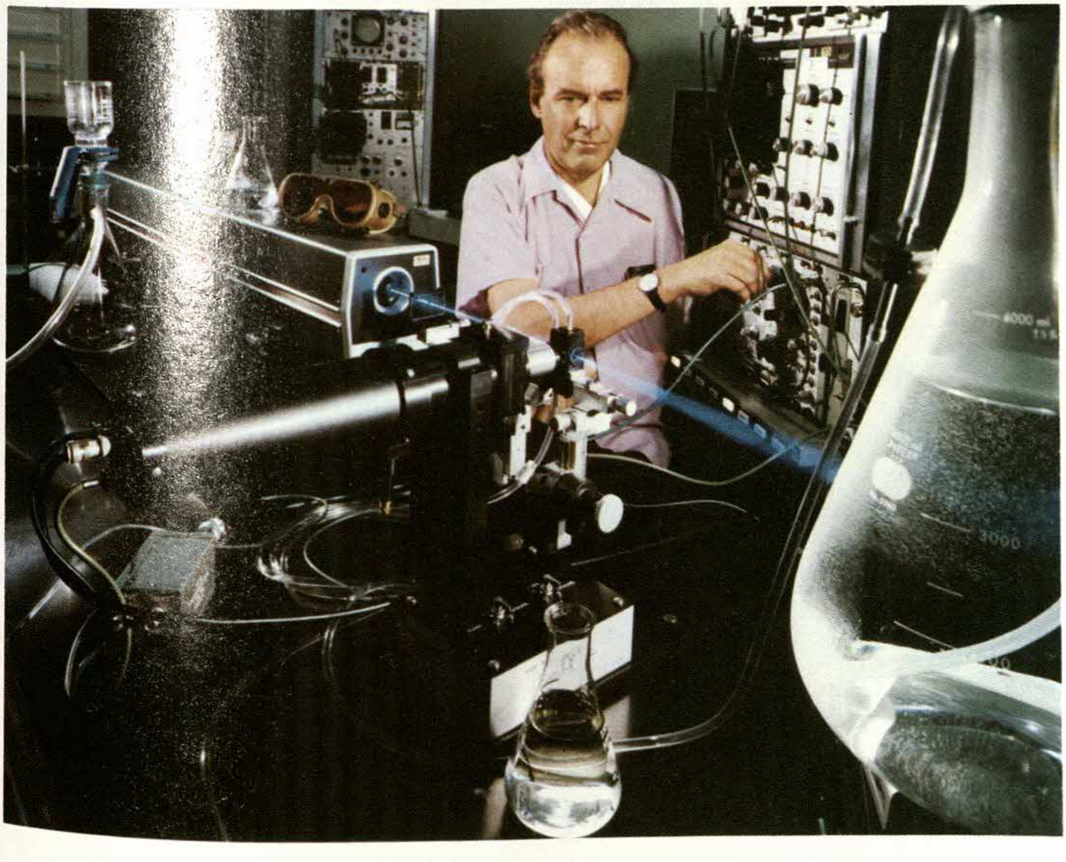


A scientist works with a liquid laser that is pumped with nitrogen dye to separate liquid molecules into their component gases.

Lawrence Berkeley Laboratory

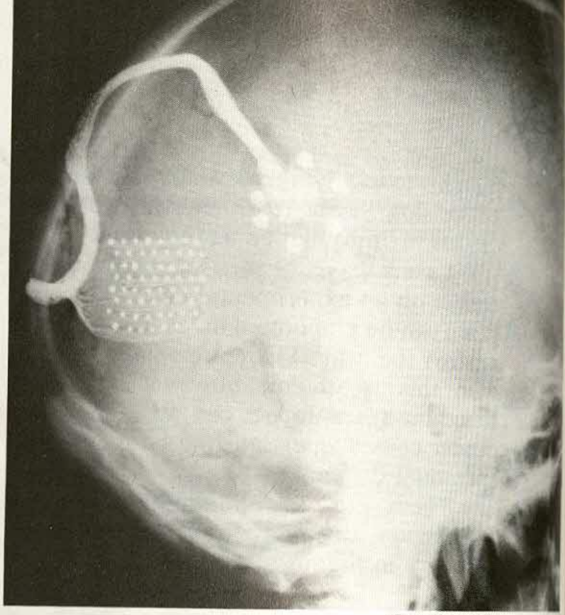
Lasers are used in biomedical research to identify and separate chromosomes, the carriers of genetic messages in cells. This technique allows scientists to study better the link between genetic material and the causes of disease.

Lawrence Livermore Laboratory



X RAYS

by Helen Merrick



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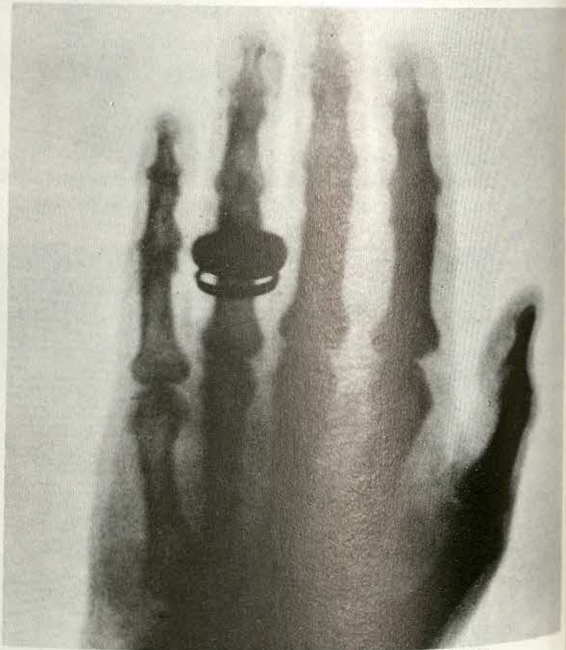


University of Utah Medical Center

X-ray techniques have become more sophisticated since the first X-ray photographs were taken. Top: a skull X ray used to check the position of a device implanted between the halves of the brain. Bottom: an early X-ray photograph taken by Roentgen himself in the late 19th century. The opaque bands are rings.

Within recent years the walls that rigidly separated physics and chemistry have been crumbling away. Prophetic of this trend, one of the first steps toward the discovery of X rays was taken by a British scientist who was both a chemist and a scientist, Sir William Crookes, in the late nineteenth century.

Crookes was interested in the effects of electrical discharges through gases at low pressure. To help him in his experiments he invented a device that became known as the *Crookes tube*. It was a tube from which most of the air had been pumped. This created a partial vacuum. Some air had to remain in the tube if it were to work. Metal wires were sealed into opposite ends of the tube. These wires served as electrodes to which a source of electric current could be attached. The current could then be sent through the air remaining in the device.

One day, after Crookes had been sending a high-voltage current through his tube, he discovered that photographic plates in a closed box nearby had become fogged. He had also observed a mysterious green glow in the tube. Crookes prevented further fogging by removing photographic plates to another room whenever the current was flowing. The strange phenomenon does not seem to have aroused his curiosity.

ROENTGEN'S DISCOVERY

Our story skips a few years, to the autumn of 1895. Wilhelm Konrad Roentgen, a German physicist, was puttering with a Crookes tube in his laboratory at the University of Würzburg. Turning on a high-voltage current, he noticed the effects that had already attracted the attention of Crookes: the green glow; the fogging of photographic plates. Roentgen was not satisfied to let it go at that. He tried covering the tube with black paper, through which no visible light could pass, and still something came through that affected a photographic plate. He came to the conclusion that this something must be invisible rays, and he called them *X rays* because "X" stands for the unknown in science. X rays are also called *roentgen rays* for their discoverer.

The story goes that Roentgen, by a lucky accident, also discovered one of the properties of X rays. While he was experimenting with the Crookes tube, some photographic plates in a desk drawer had been fogged. Instead of throwing the spoiled plates away, he developed them. On one plate he was amazed to see the perfect image of a key appear, yet no key had been in the drawer. Then he remembered that a key had been on the top of the desk. The key had been photographed right through the desk by the X rays. Roentgen also found that the rays would pass through his hand when he inserted it between the tube and a plate. In the developed photograph, however, the bones stood out clearly as dark shadows as compared with the flesh. This indicated that the bones, more dense than the flesh, must block the rays to some extent and, therefore, that the rays pass more easily through less dense materials.

The green glow that Crookes and Roentgen saw was light waves being sent out by the glass walls of the tube when electrons bounced against them, as the result of the discharge of electricity through the gas remaining in the tube. (Electrons are atomic particles that carry a negative charge of electricity; ordinary electric current is really a flow of electrons.) At the same time, the electrons were stimulating the atoms of the glass to send out waves of extremely short wavelength—the X rays. Since then, physicists have learned that X rays are produced when electrons strike any atoms at high speed and, conversely, that when X rays strike atoms, electrons are hurled out.

X RAYS AND ORDINARY LIGHT

It was finally proved that X rays are similar to those of ordinary light, though they differ in wavelength. This is how it was proved:

Since the time of Sir Isaac Newton, it had been known that visible white light consists of a number of different colors, and that white light may be broken into bands of these colors, since each color has a different wavelength. Red, at one end of the spectrum, has the longest wavelength; violet, at the other end, the shortest. When white light passes through a prism, each color is bent according to its wavelength, red the least and violet the most, and we get the rainbow array of the visible spectrum.

Diffraction is a term used for the property which waves possess of spreading out and interfering with one another when they meet a slit, a hole, or an opaque object of almost the same size as the wavelength. One kind of diffraction grating consists of a system of lines drqwn very close together on a glass plate. The lines are parallel and equally spaced and there are hundreds of them to the centimeter. The spectrum obtained from such a grating is an interference phenomenon. The waves reinforce one another when their crests, or high points, come together at any point, and cancel each other out when a crest meets a trough, or low point. The result is a system of bands of light and dark, visible on a screen placed behind the grating.

Mammography is a specialized X-ray technique that uses low-intensity radiation. It is able to detect breast abnormalities—even in their earliest stages.

American Cancer Society

DETERMINING THE NATURE OF X RAYS

A German physicist, Max von Laue, was familiar with the diffraction grating. In 1912, he had the idea that a crystal, such as diamond or rock salt, might separate X rays into beams of different wavelengths. This, of course, would prove that they do behave like light waves. A crystal came to mind because by this time physicists suspected (and later proved) that a crystal is a conglomeration of atoms arranged in a perfectly regular plan at very short distances from each other. It seemed to Von Laue that such an arrangement might act as a natural diffraction grating, with openings between the atoms small enough to diffract X rays if they really do have shorter wavelengths than those of visible light.

Von Laue's reasoning was sound. When a narrow beam of X rays was sent through a crystal, dark spots appeared on a photographic plate behind the crystal. It was found that the position of these spots depended on the different wavelengths in the X-ray beam and also on the arrangements of the atoms in the crystal.

Sir William H. Bragg, a British physicist, and his son, Sir William L. Bragg, carried Von Laue's work still further, and soon obtained clear, sharp spectrum lines with X rays. The Braggs discovered what is called the *law of crystal diffraction*. Using this law, a scientist who knows the wavelength of the X rays can find out how the atoms are spaced in the crystal. The process can be reversed. If the scientist begins with knowledge of how the atoms are arranged, he or she can then work out the wavelength of the X rays.

To describe all the experiments, theories, and calculations that were involved in this work would fill volumes. Summing up, they not only furnished the key to the nature of the X rays but also to the structure of crystals.

A TYPE OF ELECTROMAGNETIC RADIATION

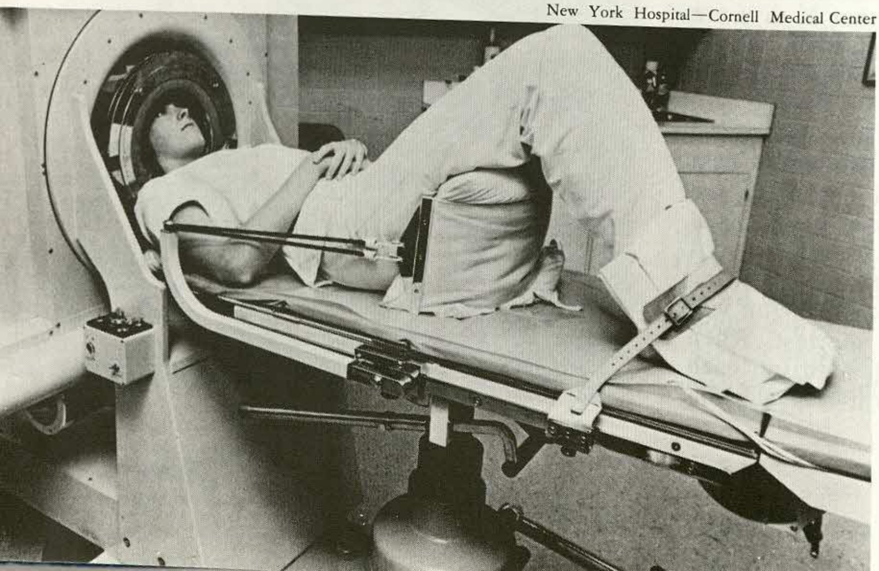
We know now that X rays are a part of the electromagnetic spectrum. They are related to radio waves, infrared rays, visible light waves, ultraviolet and gamma rays, and rays that accompany cosmic radiation. X rays belong in wavelength between ultraviolet and gamma rays. Gamma rays are given off by radium and other radioactive elements. All electromagnetic waves travel through space at the same speed—about 300,000 kilometers per second.

Wavelengths of the electromagnetic spectrum are expressed in terms of the *angstrom unit*. This unit is named for the 19th century Swedish physicist Anders Jonas Ångström. One angstrom is 1/100,000,000 (0.00000001) of a centimeter. A scientist expresses this value as $1\ \text{Å} = 10^{-8}$ centimeters. The symbol λ stands for wavelength expressed in terms of angstroms. Thus λ5,890 means "wavelength of 5,890 Å."

Visible light has wavelengths ranging from about 4,000 Å to somewhat more than 7,000 Å. The wavelengths of X rays go from about 1,000 Å to 0.1 Å, overlapping other wave groups.

An important point to remember here is that the shorter the wavelength, the

New York Hospital—Cornell Medical Center



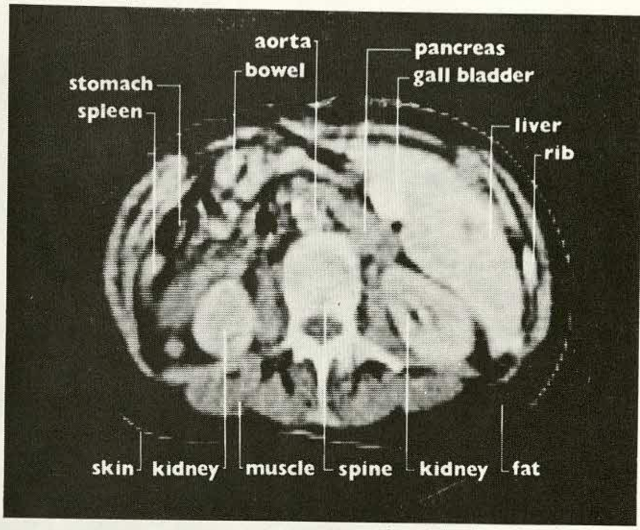
A new X-ray device—the EMI scanner—allows doctors for the first time to see the brain in cross section without exposing the patient to the risks involved in the use of some other X-ray techniques. Shown here is a demonstration of the use of the computer-aided X-ray device.

greater the energy of the ray. And the greater the energy, the more penetrating the ray will be. For this reason, X rays and the tubes that produce them can be classified as "hard" or "soft." *Hard rays* have shorter wavelengths than *soft rays* and hence are more penetrating.

THE X-RAY TUBE

A descendant of the simple Crookes tube with which our story began, the modern *X-ray tube*, works on the same principles. It consists of a bulb containing as nearly perfect a vacuum as possible and fitted with electrodes to which high voltage can be applied. The negative electrode is called the *cathode*. It is usually a filament of tungsten wire wound into a spiral. The positive electrode, the *anode*, is called the *target*. It is made of some heavy metal, such as tungsten, and is welded to a copper support, which helps conduct away the tremendous heat generated. To prolong the life of the target, many present-day tubes are fitted with rotating anodes. When an electric current of high voltage is turned on, the cathode is heated white-hot and sends out a stream of electrons, or cathode rays, which are pulled through the vacuum by the high voltage until they reach speeds of thousands of kilometers per second. They slam against the atoms of the target and, as they strike, a spurt of X rays splashes out from the disturbed material of the target.

To explain where the X rays come from, we must go inside the atom. Whirling around the atom's nucleus, or core, are one or more electrons, each in a definite orbit. If an electron is forced to jump out of its shell, some kind of ray is emitted. Visible light is sent out when an electron is displaced from an outer shell. If the disturbance is much more violent, an electron in an inner shell, close to the nucleus, is likely to be dislodged and removed from the atom entirely. The atom cannot remain in this unbalanced state. So an electron from the next outer shell jumps into the vacant place. The second shell is soon filled by an outer electron jumping in, and so on. Balance is restored when the atom picks up a free electron (there are always some free electrons drifting around in a metal) for its outermost shell. X rays are the result of inner-shell disturbance.



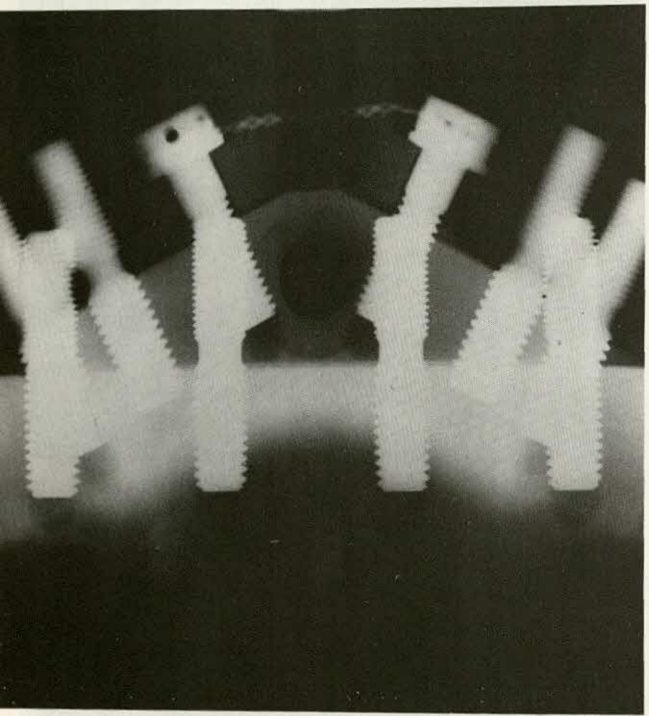
Ohio-Nuclear Inc.

The EMI scanner on the opposing page is an example of computerized axial tomography, or CAT. A pinpoint X-ray beam provides a three-dimensional view of the body. Here is a CAT-produced cross section of the human abdomen.

PROPERTIES OF X RAYS

As we have indicated, it requires more energy to displace the electrons close to the nucleus than it does to displace any others in the atom. The higher the voltage in an X-ray tube, the faster the cathode rays will be pulled through it, increasing their energy. As a result the wavelengths of the X rays given off from the target will be shorter, approaching the wavelengths of gamma rays, and the X rays will be more penetrating. In giant X-ray tubes, built to stand millions of volts, the cathode rays may reach almost the speed of light—about 300,000 kilometers per second—and X rays are produced that will easily go through a meter or more of concrete.

As we have seen, one of the first properties of X rays to be noticed was their ability to penetrate solid substances such as wood, flesh, and metal. However, X rays cannot be focused, or brought to a point, easily, as visible light-waves can. One reason for this is that an X-ray beam of the same wavelength does not penetrate all substances equally well. We mentioned ear-



General Electric

Courtesy of Radiography Inspection, Inc.

X rays are widely used in industry to discover flaws in materials. Top: shadow picture of part of an airplane crankcase, showing the position of the studs (white objects). Bottom: a portable X-ray machine is used to inspect the welded seams on a pipeline before it is buried in the ground.

lier that the depth of penetration depends partly on the density of the substance. Ordinary X rays, produced at 100,000 volts, pass through flesh easily but through bones less so. Filters of aluminum or of copper are often used to refine X-ray beams. The softest rays are absorbed even by air. One of the most effective materials to block X rays altogether is lead. For this reason, glass containing lead is used on many kinds of X-ray equipment to protect those who work with it and are endangered by X rays.

Another important property of X rays is that, like light, they act on the chemicals of photographic plates, fluorescent screens, and so on. This X-ray action together with the penetrating property makes it possible to take "shadow" pictures of, say, the inside of the human body or of a metal casting. Bombarded with X rays, some chemicals *fluoresce*—that is, they glow brightly as long as X rays strike them. One of the best-known uses to which this property has been put is in the fluoroscopic screen, which we shall explain when we take up the medical uses of X rays in more detail.

When a gas, such as the air, is exposed to X rays, it becomes ionized—that is, some of its atoms or molecules acquire an electric charge. The amount of ionization produced serves to measure the strength of the X rays.

Still another property of X rays is that when they fall on a substance, other rays are given off, which also consist largely of X rays. This *secondary radiation* is partly like that of the original X rays but is also dependent on the kind of substance exposed. It gives the scientist a tool with which to study the structure of matter.

X rays also have an effect on living things. When X rays are absorbed, they change the structure of tissues, and these will be burned or destroyed if the exposure is long enough. Some kinds of X rays are also able to affect the genes, the elements in the germ cells of reproductive organs by which hereditary traits are passed on from one generation to the next. In this way heredity itself may be changed.

USE IN ANALYZING MATTER

Considering the ability of X rays to probe matter and force it to yield its secrets, however grudgingly, it is hardly to be wondered at that X rays play a prominent role in scientific research. Practical application of new findings frequently follows so swiftly in many fields that it is difficult to separate the pure research from the everyday use.

Perhaps no field has been more rewarding to the scientist than the kind of analysis called *X-ray crystallography,* which began with the work of Von Laue and was developed further by the Braggs. The methods used in this field are too complicated to discuss within the brief limits of this article. To put it as simply as possible, when a narrow beam of X rays is sent through a crystal, the rays are scattered by the atoms, and form a balanced pattern, which can be caught on a photographic plate. Each kind of crystalline solid has its own pattern. One result of this work is that scientists now have an accurate knowledge of the character of X rays sent out by each of the chemical elements. This knowledge has helped to determine the internal structure of the atoms themselves. In fact, in what is called *X-ray spectroscopy,* the rays reveal information about the patterns of the electrons inside the atom.

From this kind of research, it has been a fairly easy step to investigate the arrangement of molecules in various chemical substances. They may be "fingerprinted" by the way in which X rays are scattered in passing through.

A comparatively recent development is the branch of science called *X-ray absorptometry.* Scientists can measure the quantity of certain materials in a chemical compound by a device that shows the amount of X rays absorbed. The device is so sensitive that it can register the difference between 99 and 100 sheets of thin paper. One practical use is to measure the amount of "ethyl" in gasoline. X-ray absorptometry is possible because atoms can absorb X rays. An atom of oxygen, say, absorbs the same amount of rays whether it is in the form of the element or in a compound with other elements. Under the simplest conditions, the amount of absorption is the same whether the substance containing the oxygen be a solid, liquid, or gas. So the amount of energy taken from a beam of X rays passing through a given mass of a substance is always the same, whether the substance is hot or cold, or a gas, liquid, or solid.

Even art has benefited. X rays can be used to analyze the composition of pigments in oil paintings—to the point where sometimes the painter of what appears to be an "old master" can be identified.

The first *X-ray microscope* was introduced in 1950. It uses a combination of X rays and visible light-waves. Because of the penetrating power of X rays, it reveals finer detail than is possible with optical microscopes.

THE BETATRON

In order to increase the penetration of X rays, scientists have been building ever more powerful machines. A giant among them all is the *betatron*—really an outsized X-ray tube. This machine was first invented in 1941 by Donald William Kerst, of the University of Illinois. He called it the "betatron," from *beta ray,* which is a stream of high-speed electrons.

As you may guess, a betatron is an enormously complicated apparatus. Essentially it consists of a doughnut-shaped glass tube, containing a vacuum, that is placed between the poles of a powerful electromagnet. An *electron gun* is arranged so that it will send a stream of electrons into the tube at a certain angle. Inside the tube, two forces act on the electrons: one makes them follow the curve of the tube, and the other gives them higher and higher speeds, increasing their energy enormously. At a chosen instant, they are bent from their curved path and directed to the X-ray target. All this happens in the twinkling of an eye. Nevertheless during this time the electrons circle the tube many thousands of times. These operations are repeated over and over again.

X RAYS AND LIVING TISSUE

In our daily lives, most of us are first introduced to X rays in the office of a dentist or a doctor. From what has been said, you can now understand why X-ray photography is so helpful in dentistry and medicine. Cavities, fractured bones, foreign matter—all can be detected with X rays.

At one time, you might have had your chest examined with a *fluoroscope,* which makes use of the property of X rays to cause certain chemicals to glow. One advantage, for some purposes, of the fluoroscope over X-ray photography is that the fluoroscope allows a doctor to observe the inside of the body in action.

A *fluoroscopic screen* consists of a piece of cardboard (which X rays can pass through easily) coated with certain crystals, such as platinobarium cyanide or tungstate of calcium, which fluoresce under X rays. In an examination, the patient stands or lies down between an X-ray machine and a fluoroscopic screen, which the doctor can place against any part of the body. In some cases, such as an examination of the stomach, the patient usually drinks a liquid first, often a compound of barium, which blocks X rays. When the current is turned on in the X-ray machine, bones and thick organs, or organs such as the stomach that are full of the barium compound, cast shadows on the screen because they are blocking the X rays, and the rest of the screen glows. For the best results in this process, of course, the fluoroscope should be used in a blacked-out room.

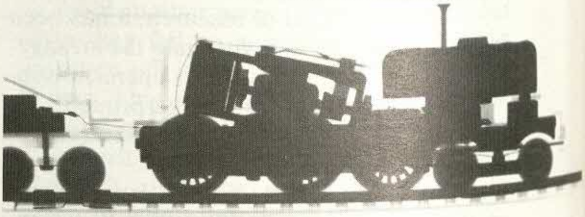
X-ray photography itself has been improved by the development of a method for taking pictures in three dimensions. The first X-ray pictures were "flat," showing only width and length. Improvements added depth, so that the inside of the body could be seen in actual perspective. Another method, invented by a Swedish scientist, Arne Frantzell, permits pictures of veins and other soft tissues such as muscles, fat, and the skin around bones to be taken in great detail. These improvements in X ray techniques have greatly improved medical diagnoses.

X rays also have a place in the treatment of disease, particularly cancer. The action of X rays on living cells is mainly a destructive one. However, young cells and actively growing ones succumb to X-ray action more quickly. Cancerous cells are usually young and grow much more rapidly than healthy ones, so it is possible to adjust the strength of the X rays and limit the exposure, with the result that only the cancerous cells are attacked and healthy cells are affected very little, or not at all.

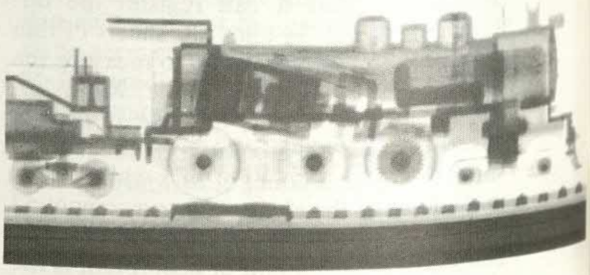
Great care is necessary. The *radiologist,* or medical X-ray specialist, must be able to control the dosage precisely, X-ray machines for medical treatments are complicated affairs, with a number of precision measuring devices. Tumors on or near the surface of the body may be treated with X rays produced at 100,000 to 200,000 volts, but tumors that lie deeper may require rays from tubes of higher voltage, running into the millions of volts. "Millions of volts" may sound alarming, but there is no danger of shock. The machines are completely insulated, and the dangerous part of the equipment is kept outside of the treatment room.

Comparison of X-radiograph and a neutronradiograph, or neutrograph. The radiograph highlights the metal structures of the locomotive. The neutrograph shows the nonmetal structures more clearly. Neutrons and X rays have different properties.

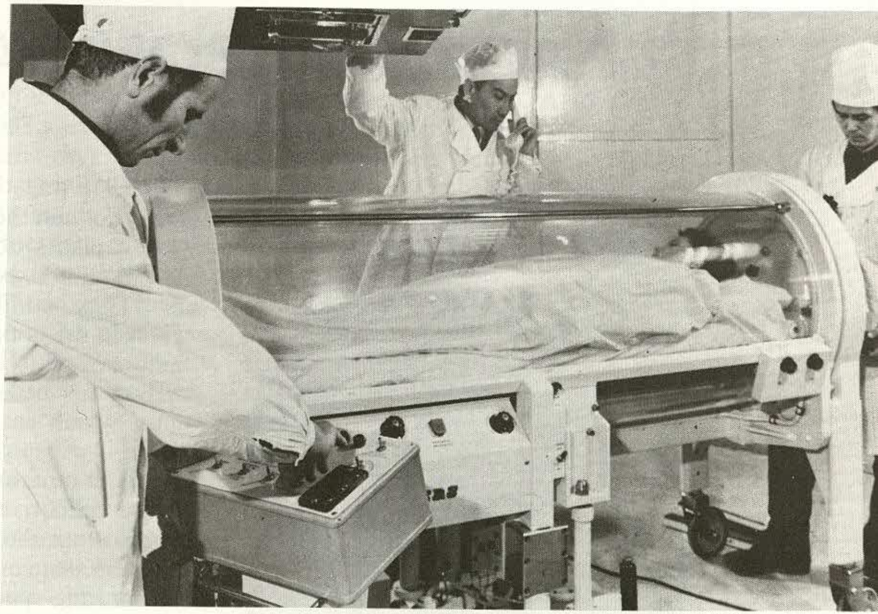
General Electric Neutrography Service



X-RADIOGRAPH



NEUTROGRAPH



High-intensity X-rays are produced in the betatron. These Soviet radiologists are preparing a patient for radiotherapy treatment.

UPI Photo

Many cases of malignant tumors, considered hopeless, have even been successfully treated with radiation therapy. There were no harmful effects from the treatment on the patients, and the tumors that could be examined had shrunk.

Improvements in X-ray-treatment techniques are coming fast. An X-ray shield, developed by Dr. Hirsch Marks, of the New York City Cancer Institute, is one example. It permits extremely high-voltage X rays to be trained on a tumor without damage to healthy cells. Radiation dosage is measured in terms of a unit called the *roentgen*—*r* for short. Without the shield, the highest safe dosage is about 200 r in air per treatment, up to a total of 3,300 r over a period of four weeks. With the shield, Dr. Marks reported, 1,200 r in air a day may be given for twenty days of treatment—in all, 24,000 r.

Materials such as plant and animal tissues take internal pictures of themselves in a technique known as *radioautography*. The tissues are impregnated with substances that emit radiation, which is recorded and enlarged on sensitive film.

X RAYS IN INDUSTRY

The industrial applications of X rays are legion, and we have space to mention only a few here. X rays are used to examine metal coatings, plastics, rubber insulation, and so on, whose flaws might not appear on the surface. High-pressure boilers and pipes, for instance, are X-rayed to be sure that there are no weak places that might cause explosions. Some machines are large enough to take an X ray of an entire automobile. Most X-ray machines, however, concentrate on smaller areas.

NEW TECHNIQUES UNDER DEVELOPMENT

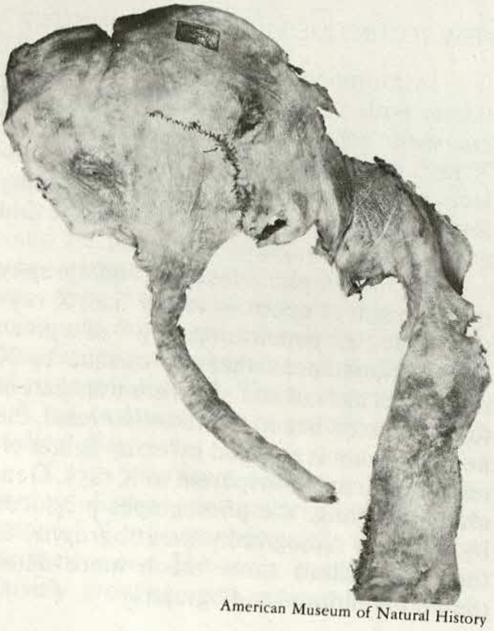
Instantaneous pictures and movies are taken with X rays—so-called *flash* and *cinematic radiography*. An intense burst of X rays captures images of fast-moving objects on film and shows what is happening inside these objects, such as projectiles and even human beings.

For example, *neutron radiography* uses a beam of neutrons rather than X rays to produce a "penetrating view" of a given object. Substances that are opaque to X rays, such as lead and steel, are transparent to the neutron beam. On the other hand, the neutron beam is stopped by many lighter elements that are transparent to X rays. Generally speaking, the photographs produced by neutron radiography (*neutrographs,* as they are called) show much more detail than conventional radiographs.

RADIOCARBON DATING

by Willard F. Libby

Jericho Excavation Fund



American Museum of Natural History

All living things, plants and animals alike, contain the chemical element carbon. Green plants obtain carbon from the carbon dioxide existing in gaseous form in the air. They combine this substance with water in the presence of sunlight and manufacture food. They become the source of carbon for other plants and also for animals, which eat plants or plant-eating animals.

A comparatively insignificant number of the carbon atoms existing in all living things are radioactive; that is, their nuclei disintegrate sooner or later, sometimes after a long span of time. Radioactive carbon atoms continue to exist in animals and plants—and in objects made from them—for thousands of years after death has taken place. We find radioactive carbon in the hard parts, soft parts, and manure of animals that died long ago; in peat (derived from dead vegetation); in wooden boats and platforms; in cotton and linen garments; in leather shoes and bags; and in many other plant and animal derivatives.

A MATTER OF ISOTOPES

Scientists have found a practical application for the radioactive carbon atoms existing in dead organic matter. By carefully measuring the radioactivity of samples derived from such matter, they have developed a method for dating objects that go back to ancient and late prehistoric times.

The radioactive carbon atoms that make possible this dating method are isotopes with mass number 14: *carbon-14 atoms*. The vast majority of carbon atoms are isotopes with mass number 12. Carbon-12 atoms are not radioactive.

Radiocarbon dating method has been applied to date the two objects shown above. The skull was not dated directly, but charcoal in the layer where the skull bones were found was dated at 7,813±160 years. The bottom photo shows the frozen remains of a baby woolly mammoth dated at 21,300±1,300 years.

How is radioactive carbon-14 produced? The answer is to be found in the upper reaches of the earth's atmosphere. This area, filled with tenuous gases, is constantly bombarded by cosmic rays—radiations coming from outer space, probably from beyond our galaxy. As the rays strike the atmosphere, they disintegrate the nuclei, or cores, of some of the atoms that are found there. Among the building blocks that make up the nuclei are the particles called *neutrons*. When nuclei are smashed by cosmic rays, free neutrons are scattered in the air.

They are very quickly absorbed by the nitrogen atoms, with mass number 14, that make up about 78 per cent of the atmosphere by volume. When a nitrogen atom absorbs a neutron, a proton—a particle with a positive charge of electricity—is emitted. The atom keeps its mass number, 14, but instead of remaining a stable nitrogen atom, it becomes an unstable, radioactive carbon atom, with mass number 14.

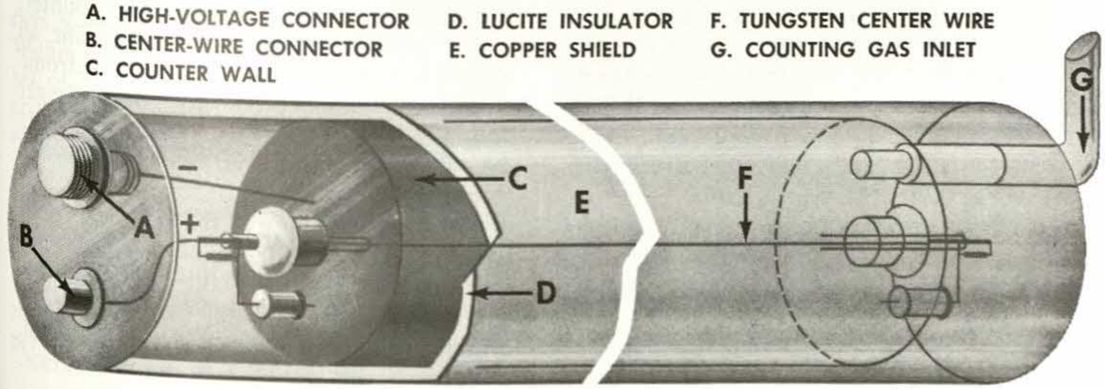
Radioactive carbon, or *radiocarbon*, as it is often called, has a *half-life* of 5,730 years. By that we mean that if we start with 100 atoms of radiocarbon, at the end of 5,730 years we shall have only 50 atoms, or half as many. The rest will have decayed. In the next period of 5,730 years, one half of the remaining 50 atoms—that is, 25 atoms—will also decay and so on.

Cosmic rays have been bombarding the atmosphere for millions of years, and they have been constantly producing new supplies of radiocarbon. At the same time the radiocarbon atoms that have already been formed are steadily disintegrating. It is as if water were being pumped into a tank with a hole in its bottom. A steady level will be reached in the tank when the amount of water entering it will be equal to the amount of water flowing out of it. By analyzing the corresponding "level" of carbon-14 atoms, scientists have calculated that there are about 50 metric tons of radiocarbon on the earth at any given time. In each second upon each square centimeter of the earth's surface, something like 2.4 disintegrations of radiocarbon are taking place—that is, 2.4 atoms of radiocarbon are decaying. This represents a considerable amount of radioactivity, and it is surprising that it is not noticed ordinarily. The reason for this state of affairs is that the radiocarbon that is produced in the atmosphere is always diluted with a tremendous amount of ordinary carbon.

WHERE C-14 GOES

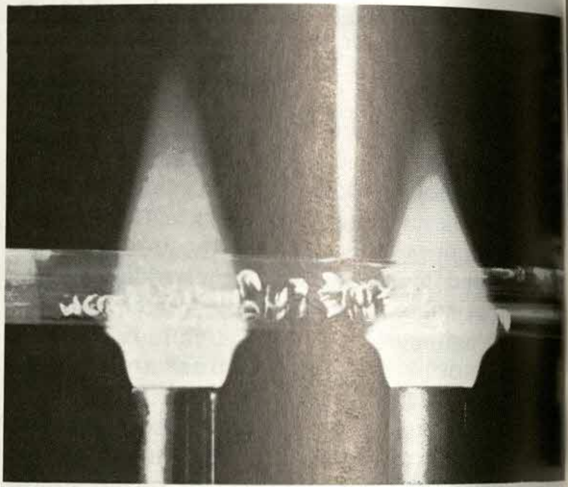
What happens to the radioactive carbon atoms on the earth's surface? We know that under the appropriate circumstances ordinary carbon atoms combine with the oxygen atoms in air and burn, forming carbon-dioxide molecules, or, if combustion is incomplete, carbon-monoxide mole-

Low-level gas proportional counter used extensively in radiocarbon dating. Pure carbon dioxide, derived from a sample of the object that is to be dated, is sent into the counter, which has been appropriately charged. The gas introduced into the counter contains both stable carbon (C-12) atoms and radiocarbon (C-14) atoms. The text describes what happens when a radiocarbon atom disintegrates.



Isotopes, Inc.

Steps in the radiocarbon dating of a wooden object. Near right: after a sample is taken from the object, it is burned in an oxygen atmosphere. The gas that is formed consists of carbon dioxide plus various "impurities." Opposite page, left: The impurities are removed in a vacuum system, and the purified gas is stored. Opposite page, right: The carbon dioxide is piped into a counter (the central cylinder in the photo), and the disintegrations of radiocarbon atoms are recorded. Note the concentric counters that surround the central cylinder. They will absorb cosmic rays; therefore the latter will not affect the central counter.



cules. That is what happens, for example, when we set fire to coal, which is made up largely of carbon. We take it for granted, therefore, that the radiocarbon atoms upon the earth will combine sooner or later with oxygen atoms and will produce radioactive carbon-dioxide molecules plus a certain quantity of carbon-monoxide molecules.

There is a considerable amount of nonradioactive carbon dioxide in the air at all times. Winds thoroughly mix together the radioactive and nonradioactive molecules of carbon dioxide. Plants assimilate small amounts of radioactive carbon dioxide together with large amounts of ordinary carbon dioxide. That is why they and the animals that feed upon them, directly or indirectly, contain radiocarbon.

MEASURING DECAY

As long as plants and animals live, they keep replenishing their stores of radioactive carbon. They can no longer absorb it, however, after they die. The radiocarbon atoms they contain at the moment of death will disintegrate at the rate of 50 per cent every 5,730 years, and they will not be replaced.

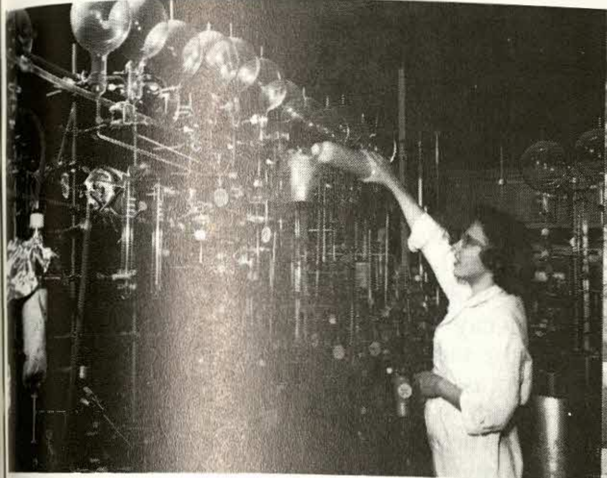
While the organism is alive, there are 15.3 disintegrations per minute for every gram of carbon that it contains. At 5,730 years from the time of death, there will be 7.65 disintegrations (half of 15.3) per minute; 11,460 years from the time of death, there will be 3.83 disintegrations (half of 7.65) per minute, and so on. At the end of 20,000 or 30,000 years, the disintegrations will be so few that it will be exceedingly difficult to measure them. By noting the rate at which the radiocarbon atoms in a given sample decay, we can estimate the age of the sample—the time that has elapsed since death. That is the principle of radiocarbon dating.

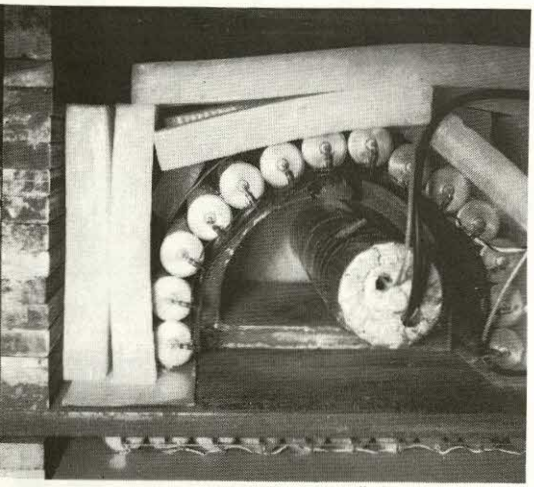
MEASURING DEVICES

In order to measure the rate of disintegration of radiocarbon atoms, we use a special Geiger counter. This instrument is shaped like a cylinder and has a wire extending down its center. It is filled with gas. An electrical potential is maintained between the wire and cylinder walls, which have been appropriately charged.

As an atom disintegrates, it emits a beta particle. When this particle passes through the gas-filled space of the counter, a tiny spark is produced. At this point, an electrical impulse is recorded by electronic equipment connected to the Geiger counter. The sensitive instrument detects every disintegrated particle that passes through the gas within it.

A small sample of the material to be dated is taken and chemically purified. Purification removes any contamination that entered the material after the death of the organism that had supplied this material. Otherwise the dating will be inaccurate.





all photos, Isotopes, Inc.

The sample is then burned into carbon-dioxide gas, which contains the original carbon-14. The gas, also purified, is led into the counter, which records the carbon-14.

Unfortunately the radiocarbon in the sample is not the only source of radiation that affects the Geiger counter. Even before the radioactive sample has been placed in it, the instrument records some 2,600 counts a minute. These have been produced by external radiation, derived from such sources as uranium and thorium deposits and cosmic rays.

The radiations from uranium and thorium deposits and their disintegration products can be effectively absorbed if one places 15 to 20 centimeters of iron around the Geiger counter. But cosmic rays, an important source of external radiation, are so penetrating that they cannot be warded off by a shield of iron. Hence, instead of trying to shield the Geiger counter from these rays, we must "erase" them from the record. Within the external iron shield, we place a set of Geiger counters, in close contact, around the central counter that contains the radiocarbon sample. The outside counters are then connected electronically so that whenever cosmic radiation passes through one of them, the central counter is turned off for a fraction of a second.

By utilizing the iron shield and the concentric Geiger counters, the 2,600 counts per minute produced by external radiation can be reduced to 15 or 16 per minute. The sample can then be analyzed.

DATING A SAMPLE

By measuring a given sample for about twenty-four hours, it is possible to determine its age, with a certain margin allowed for error. The symbol ± (plus or minus) is used to indicate this margin. For example, if the age of a given sample is given as 11,044 ± 500 years, the age-range will be from 10,544 to 11,544 years.

The sample to be dated may be a piece of wood, charcoal, or peat, or it may be a fragment of cloth or a shell. The sample should contain at least 10 grams of pure carbon. The average radiocarbondated sample weighs about 30 grams.

Radiocarbon dating is especially useful for material whose age can be checked against historical records. Close agreement often occurs between the two dating methods. But for prehistoric artifacts, some other way must be found to calibrate radiocarbon dating.

OTHER METHODS OF DATING

Other methods of dating prehistoric materials have been developed, and refinements are continually being made.

DENDROCHRONOLOGY

One that offers considerable help is *dendrochronology*, or tree-ring dating.

This gives the ages, in years, of ancient trees and logs, especially those used in prehistoric constructions. Trees in temperate climates grow by adding a ring of wood to the trunk each year. By studying the growth rings of trees and logs in a given region, archaeologists can derive a system of dating for them.

From comparisons of radiocarbon dating with the dendrochronology of certain trees, it has become evident that corrections of a few hundred years must be made in radiocarbon dates from about 5500 B.C. to 1500 B.C. This error in radiocarbon chronology may be caused by past variations in the intensity of cosmic rays coming to earth.

USE OF OTHER RADIOACTIVE ELEMENTS

Isotopes other than carbon-14 are now also used to date objects. The principles used to calculate the date are basically the same as those of radiocarbon dating. Among the radioisotopes used for dating are uranium, potassium-40, rubidium-87, and samarium-147.

Uranium decays to form lead. Many minerals contain uranium, lead, and other elements. Knowing the half-life of uranium and the ratio of uranium to lead in a sample mineral, scientists can use this information to calculate the age of the mineral. There are some problems, however. The calculated age is valid only if you can assume that no lead has been added to the sample from processes other than radioactive decay and that no lead has leached from the sample.

Potassium-40 decays to form argon-40. Both isotopes are present in many rocks. The ratio of the two isotopes, plus the known half-life of potassium-40—1.3 billion years—enables scientists to date the rocks. But argon is initially present in many rocks. Therefore, samples that give the most accurate results are those that have lost their initial argon early in their history.

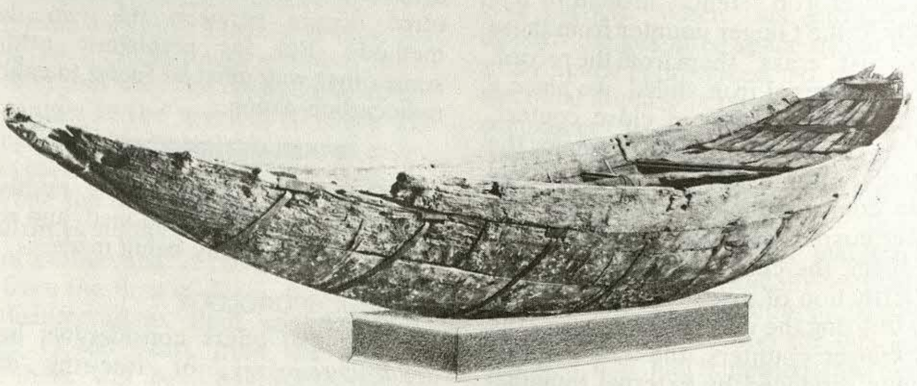
The decay of rubidium-87 (half-life 50 billion years) to form strontium-87 and of samarium-147 (half-life 100 billion years) to form neodymium-143 has been used to date some of the oldest known rocks.

EGYPT

Wood from the deck of the great funerary ship from the tomb of King Sesostris III. Known age: 3,750 years. This remarkable boat is now in the Chicago Museum of Natural History. It is about 3.5 meters long and has a beam of about 2 meters. The sample was obtained by sawing a hole in the deck.
3,621 ± 180

A piece of acacia wood beam in an excellent state of preservation from the tomb of Zoser at Sakkara. This tomb has a known age of 4,650 ± 75 years.
4,650 ± 75

Wheat and barley grain found in a granary in the province of Faiyum.
6,095 ± 250



Funerary ship from the tomb of King Sesostris III.

Courtesy, Field Museum of Natural History, Chicago.

ENGLAND

Birchwood platform from the human occupation site at Lake Pickering, in Yorkshire.
9,488 ± 350

Stonehenge

Charcoal sample from the famous stone monument of Stonehenge in Wiltshire, England. The holes outside the outer circle of immense stone blocks were probably used for some kind of ritual. The charcoal sample was found in one of the holes.
3,798 ± 275

FRANCE

Lascaux Cave, Dordogne

Charcoal sample from the floor of the Lascaux Cave, near Montignac, in the department of Dordogne. This cave is famous for its colored paintings (of animals) executed in the Old Stone Age.
15,516 ± 900

UNITED STATES

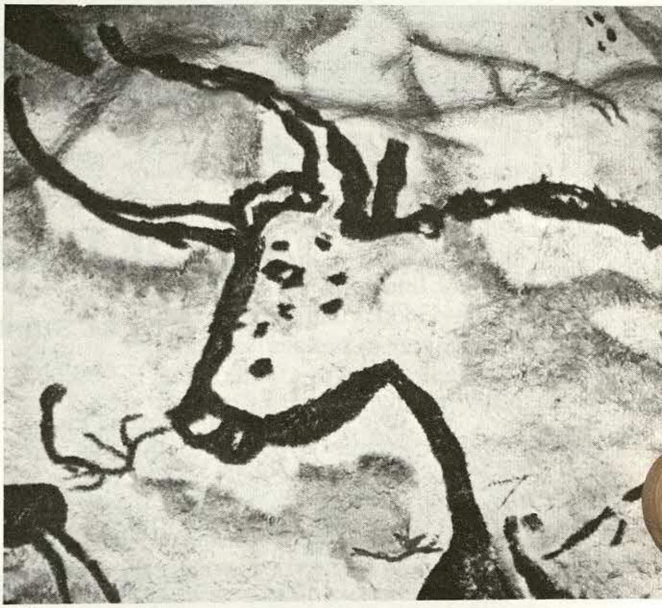
Near Las Vegas, Nevada, is an ancient cave closed by accident many thousands of years ago. In this cave, the floor is covered to a depth of some 2.5 meters with the manure of the extinct giant sloth. Manure from the lower part of the pile was used as a sample.
10,455 ± 340

In a cave known as Fort Rock Cave in Oregon were found some 300 pairs of woven rope sandals. The beautifully made sandals were used directly for the measurement of radiocarbon content.
9,053 ± 350

Crater Lake

Crater Lake, in Oregon, was created by the eruption of an ancient volcano. Apparently the eruption blew off the top of the mountain, covering the whole countryside with lava and pumice and burning or charring the nearby forests. The sample used in this case was charcoal from a tree charred by glowing pumice.
6,453 ± 250

E. Johnson, DeWys



EPA

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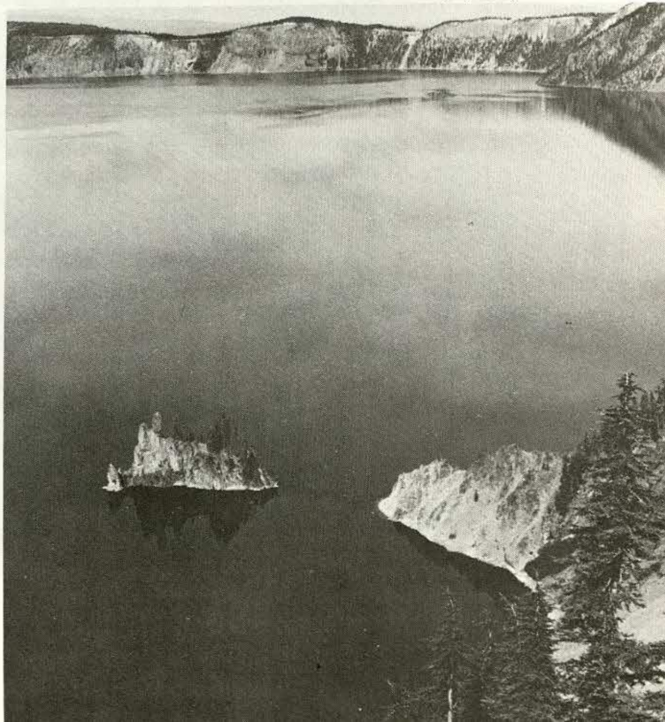


Lawrence Livermore Laboratory

Engineers check linear accelerator at Lawrence Livermore Laboratory.

ATOM SMASHERS

by M. Stanley Livingston

We owe much of our present knowledge of atomic structure to the machines called *particle accelerators,* or atom smashers. These machines accelerate, or speed up, charged particles—negatively charged electrons or positively charged protons, deuterons, or alpha particles—to high energies. Electrons are the particles of negative electricity that circle the nucleus, or inner core, of atoms. Protons, deuterons, and alpha particles are all positively charged nuclei. A proton is the nucleus of an ordinary hydrogen atom; a deuteron, of a heavy hydrogen atom; an alpha particle, of a helium atom.

The charged particles in question are kept moving in a more or less clearly defined path. Particle accelerators can be compared to electric generators, which cause a stream of electrons to flow in a wire circuit. The chief difference is that the particles in an atom smasher are not contained within a conducting wire. They must be directed and focused by magnetic and electric forces while they are being accelerated, or speeded up.

When the particles reach great enough speeds, they can be directed against a *target*. Upon striking the target, the accelerated particles may cause the nuclei of atoms in the target to disintegrate or may affect them in other ways. By analyzing records that are made of these interactions, researchers can probe the structure of the atomic nucleus.

The laws governing charges that move within electric or magnetic fields apply to accelerators. An electric field causes a charged particle to move in the direction of the field. The force exerted by a magnetic field on a moving charged particle is at right angles to the direction of motion and to the direction of the field. In the simplest case of a uniform magnetic field, the particles travel in a circular orbit. Both electric and magnetic fields can be made to vary by means of various techniques.

TWO TYPES OF ACCELERATORS

There are two basic types of atom smashers—the *straight-line* or *linear accelerator* and the *circular* or *magnetic accelerator*.

In the straight-line method of acceleration, the particles move along the axis of a number of cylindrical electrodes set in a straight line within a vacuum chamber. The particles gain energy every time they cross the gap from one electrode to the next. In the meantime they are focused in a narrow beam on the axis by electrical fields that serve as a guiding "gun barrel."

In circular accelerators, a magnetic field causes the particles to travel in more or less circular orbits within a flat cylindrical or ring-shaped vacuum chamber. The particles pass many times through fixed electrodes, each time receiving a boost in energy. They are focused into a flat, narrow beam, by magnetic or electric fields.

In the pages that follow we shall describe the most important types of accelerators. We shall show the developments that have led to atom smashers of higher and higher energy.

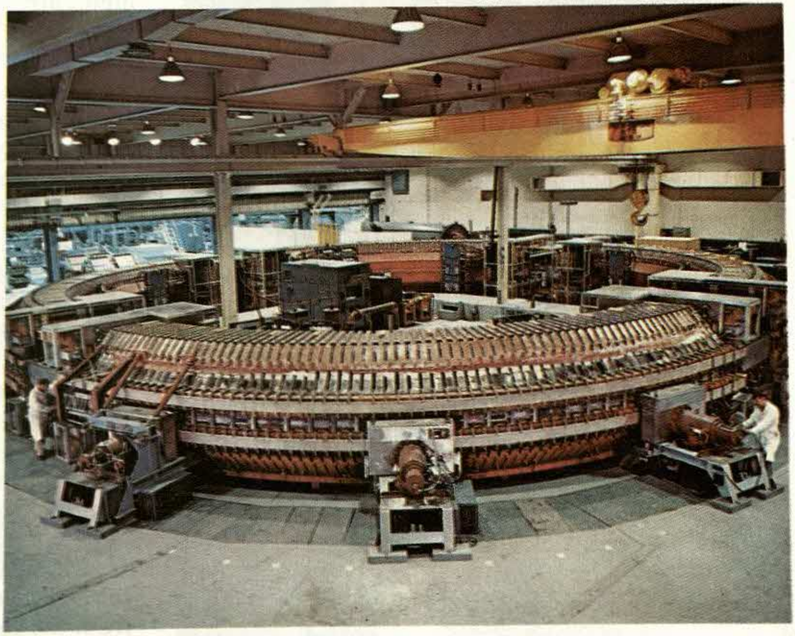
THE VOLTAGE MULTIPLIER

The first particle accelerator to disintegrate or smash atomic nuclei was the voltage multiplier. This instrument was developed by two British physicists, J. D. Cockcroft and E. T. S. Walton, in the Cavendish Laboratory of Cambridge University, England, in 1929. In 1932 it smashed an atomic target for the first time. The machine produced hydrogen ions of 400,000 electron volts. In atomic physics, energies are expressed in terms of electron volts. An *electron volt* represents the energy gained by an electron or a singly charged positive ion when it is accelerated through a potential difference of 1 volt. Cockcroft and Walton were awarded the Nobel Prize in physics in 1951 for their pioneer work.

The voltage multiplier consists of a high-voltage alternating current transformer and two banks of *condensers*. A condenser, also called a *capacitor,* is a device that holds or stores an electric charge. The condensers are connected by *rectifiers,* which serve as switches. The transformer charges one bank of condensers, through the rectifiers, in one half-cycle of the alternating current. Other rectifiers distribute the charge to another bank of condensers in the following half-cycle. The total voltage is several times the original. Cockcroft and Walton ultimately reached a voltage of 800,000. The maximum practical energy is limited by insulation breakdown to about 1,500,000 electron volts.

The voltage is applied across the terminals of a long multielectrode vacuum chamber. Charged hydrogen ions, or pro-

Brookhaven National Laboratory



The cosmotron at Brookhaven National Laboratory in New York is a proton synchrotron capable of developing energies up to 3 GeV (3,000,000,000 electron volts).

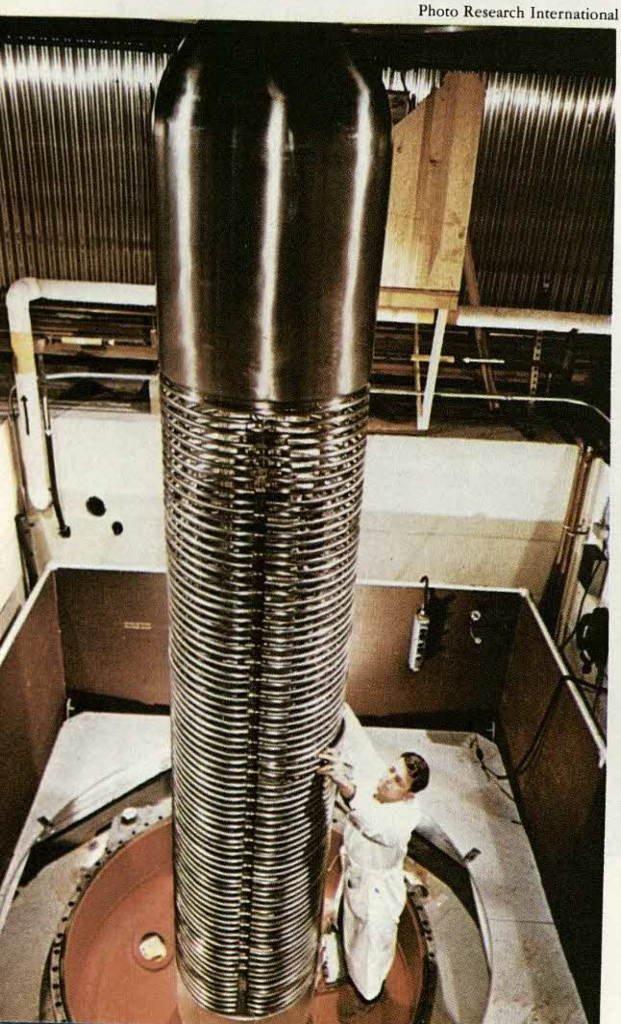
tons, released from an ion source at one end of the vacuum chamber, are speeded up by the high voltage. At the end of the chamber they strike a target and cause its atoms to disintegrate. The simplicity of the voltage multiplier has made it an important tool for certain kinds of low-energy research. It is used today in many scientific laboratories.

THE ELECTROSTATIC GENERATOR

The *electrostatic,* or *Van de Graaff, generator,* developed by Robert J. Van de Graaff at Princeton University in the early 1930s produces much higher voltages than the voltage multiplier. It is based on a familiar electrical phenomenon—the generation of a charge of static electricity by means of friction.

A Van de Graaf electrostatic generator. Charged particles in a high-voltage terminal at top are accelerated downward through a vacuum chamber.

Photo Research International



The device was first used for nuclear studies by M. A. Tuve, L. R. Hafstad, and O. Dahl at the Carnegie Institution in Washington, D.C., in 1934. It was later improved by Van de Graaff and others. The modern electrostatic generator represents the combined efforts of many researchers.

In this machine the electric charge accumulates on a hollow sphere of metal, supported on insulating columns. A motor-driven belt of a nonconducting material, such as rubberized fabric, extends between the base of the columns and the inside of the shell. An electric charge (either positive or negative) is applied to the belt at the lower end. The charge is carried on the belt to the inside of the hollow sphere and is transferred to the sphere. The potential rises steadily as charge accumulates on the hollow sphere. The process continues until an extremely high voltage is reached. Electric charge then leaks away about as fast as it is collected from the belt.

For the acceleration of particles in the electrostatic generator, a vacuum chamber is connected between the high-voltage sphere and the ground. This chamber consists of a column made up of glass or porcelain cylinders joined end to end and sealed. The particles that are to be accelerated are introduced into the vacuum chamber at the high-voltage end and accelerated down the tube. They emerge as a narrow beam and strike a target, set within the vacuum chamber. The beam can also be led from the chamber through a thin foil vacuum window for certain kinds of experiments.

If the generator is to accelerate protons, positive charges are sprayed onto the belt. Hydrogen ions (protons) are supplied to the vacuum chamber. If electrons are to be speeded up in the device, a negative charge is sprayed onto the belt. The vacuum chamber receives electrons from a hot cathode. The housing around the sphere and the insulated column is usually filled with nitrogen gas at a pressure of about 14 newtons per square centimeter. The pressure increases the insulating properties of the gas, and prevents sparks or leakage from the terminal or along the belt.

Voltages of from four to nine MeV (million electron volts) can be attained in electrostatic generators. The generators can be mounted vertically, as in the diagram shown here, or horizontally. The machines are commercially available, and are used for various purposes. Among the various services that electrostatic generators render is the sterilizing of packaged foods and drugs by means of high-energy electrons.

LINEAR ACCELERATORS

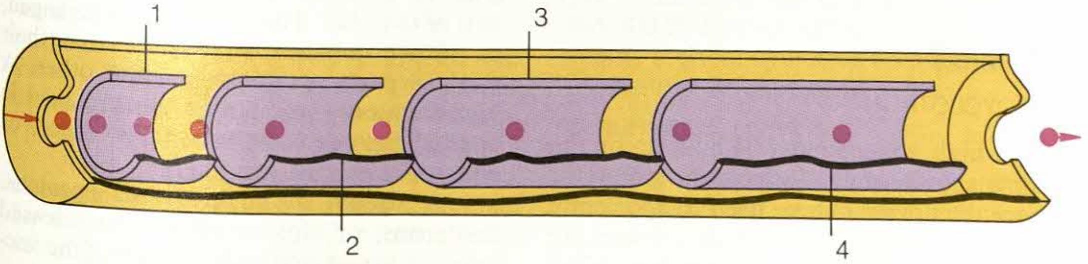
In *linear accelerators* an oscillating electric field of constant frequency is applied to a series of electrodes set in a straight line. The first linear accelerator was built by R. Wideröe in Switzerland in 1929, but was not very successful. Lack of adequate power sources of the appropriate frequencies delayed the development of linear accelerators for many years. The first successful one, used to accelerate protons, was completed by Luis W. Alvarez at the University of California in 1948. Linear accelerators are also called *linacs* (from LINear ACcelerators).

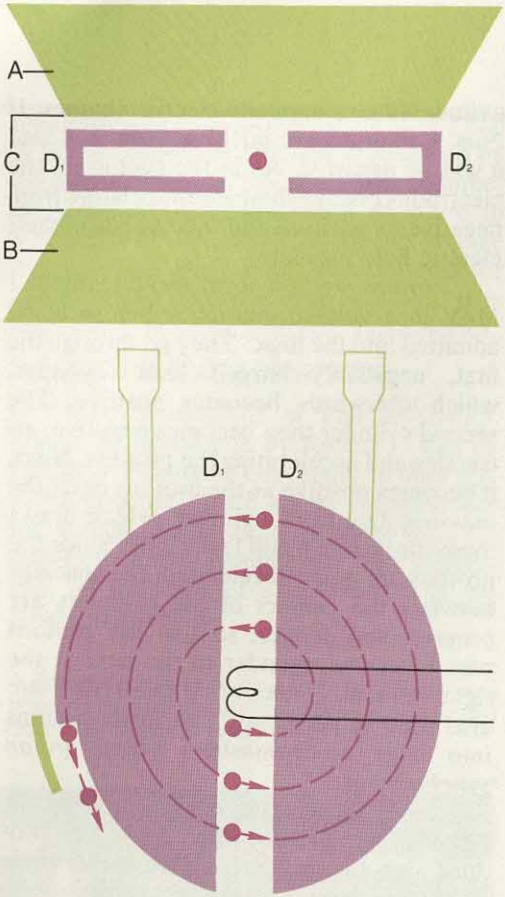
In the proton linear accelerator, the electrodes consist of a series of hollow cylinders. The odd-number cylinders are connected to one pole of a generator of alternating current; the even-number cylinders are connected to the other pole. Adjacent cylinders carry opposite electric charges. If Nos. 1, 3, and 5 are positive, Nos. 2, 4, and 6 will be negative. As in the cyclotron, the electrodes change their electric charge from negative to positive and vice versa as their electric field oscillates.

Protons are first accelerated to about 1 MeV in a voltage multiplier before being admitted into the linac. They go through the first, negatively-charged linac cylinder, which afterwards becomes positive. The second cylinder then becomes negative, attracting and accelerating the protons. Next, it becomes positive as the protons enter the now-negative third cylinder, which draws them through at a still faster rate. Since the protons are being accelerated, the spacings between the centers of the cylinders are progressively longer, so that the protons pass from one cylinder to the next at the right moment. Linacs of up to 50 MeV are also used to accelerate and inject protons into huge atom-smashers called *proton synchrotrons.*

Linear accelerators of a somewhat different type have been constructed to produce high-energy electrons. In the *electron linear accelerator,* disks with holes in the center are set in a copper tube so as to form a number of sections. The disks in the first section of the accelerator are placed at increasing intervals along the tube. A high-frequency oscillating electric field is in-

A linear accelerator for positively charged particles. The odd-number cylinders are connected to one pole of a generator of electric current; the even-number cylinders, to the other pole. Adjacent cylinders carry opposite electric charges, which change from negative to positive and vice versa as the electric field oscillates. Positive ions are led into the accelerator. They pass through the first cylinder while it is negatively charged. Next, they are attracted to the second cylinder, which has acquired a negative charge in its turn, and so on. Since the ions move faster as they pass through the cylinders, the spacing between cylinder centers has to be of increasing length, so that the ions will reach the gaps between cylinders at the right time.





The greatly simplified diagrams on this page show the workings of a typical cyclotron. At the top is a vertical cross section through the magnetic poles (A and B) and the vacuum chamber (C) between the poles. In the vacuum chamber there are two hollow, semicircular electrodes called dees (D_1 and D_2). These electrodes have opposite electric charges. The voltage is alternated so that the charges change from negative to positive and from positive to negative at regular intervals. The positive ions that are to be accelerated are released from an ion source at the center of the vacuum chamber between the two dees. Since the ions are positive, they are attracted to the negative dee. They enter the hollow electrode and their path is bent in a circle by the magnetic field (bottom). After making a half turn, the ions again enter the gap between the dees. The formerly positive dee has now become negative and it attracts the ions, which make a half turn in it. The stream of ions keeps spiraling around in this way until at last it emerges from the vacuum chamber. It can be made to strike a target or pass through a channel.

troduced into the tube. The wave length is determined by the distance between disks, while the frequency remains constant. When electrons are admitted into the tube, they remain in step with the traveling wave and increase steadily in velocity. This velocity approaches the constant velocity of light when the electrons attain several MeV energy. With any further increase in energy only the mass of the electrons increases. The disk spacings become constant, and the oscillating electric field travels along the tube at the velocity of light.

Stanford University in California has an electron linac of 20 GeV (1 GeV = "giga-electron-volt," or 1,000,000,000 electron volts.)

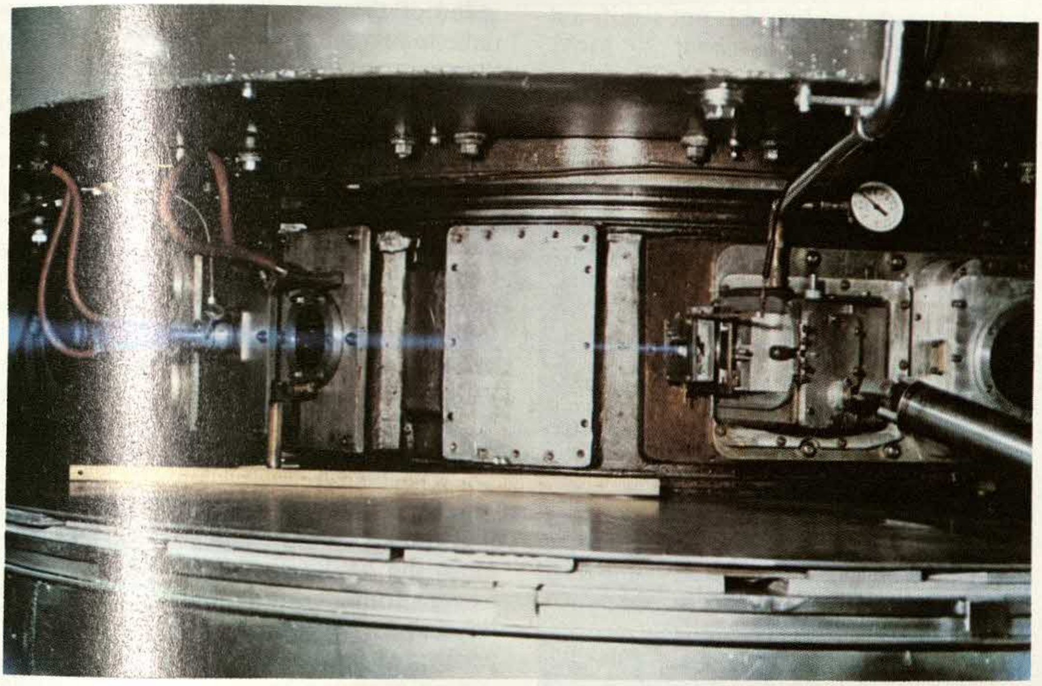
THE CYCLOTRON

A high voltage must be built up on the hollow sphere of an electrostatic generator before the device can be used to accelerate particles. In the *cyclotron,* high voltages are not required. Particles are accelerated as they pass many times through the same low-voltage electric field.

The cyclotron was first proposed by Ernest O. Lawrence at the University of California in 1930. The first operating cyclotron was built by Lawrence and M. Stanley Livingston in 1932. It produced 1.2 MeV protons. The device was immediately put to work in studying the disintegration of lithium and other targets. Continued development at the University of California laboratory and other research centers has resulted in the high-intensity cyclotrons of today. These machines have become the "workhorses" of nuclear research laboratories.

The cyclotron consists of a flat vacuum chamber set between the circular pole faces of a large electromagnet. In the vacuum chamber there are two hollow, semicircular electrodes, called *dees* because when seen from above, each has the shape of the letter "D." Each electrode is like a hollow box, entirely enclosed except for the straight part of the "D." The two dees are arranged, as shown in the diagram, so that their straight parts are close to each other. A high-frequency oscillating electric field is applied between the two hollow dees, or electrodes.

A stream of positive ions—protons, deuterons, or alpha particles—is released from an ion source in the center of the vac-



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A close-up of this cyclotron shows the deuteron beam passing through a vacuum chamber between two magnet poles, and directed toward a target.

uum chamber between the two electrodes. Since the ions carry a positive charge, they are attracted to the negative electrode. After they pass into the hollow electrode, the electric field will no longer act upon them. But they are now affected by the uniform magnetic field produced by the electromagnet. This causes the path of the particles to be bent in a circle. After they have made a half turn, they again enter the gap between the electrodes. By this time the polarity of the electrodes has changed. The negative electrode has become positive, and the positive one negative. The positive ion stream is attracted by the negative electrode, which speeds it up. It is as if one were giving a person on a swing a series of pushes. If these are timed properly, the swing will rise higher in the air. The stream of ions is also given a series of vigorous "pushes" as the result of proper timing.

As the stream passes into the second electrode, it traverses a circular path that has a rather larger radius. The ions gain in velocity every time they cross the gap. They spiral outward in their course until they reach the outer part of the vacuum chamber. They then emerge from the chamber and strike a target placed in their path. Sometimes they are directed through a narrow channel for other experiments.

The magnets of cyclotrons are built of soft-steel castings. They must be large in order to provide high energies. The pole face of a typical cyclotron magnet may have a diameter of 200 centimeters, and the magnet itself may weigh 225 metric tons. The pole faces are slightly concave. As a result, the accelerated particles are focused into a narrow beam, which circulates in a plane parallel to and halfway between the top and bottom of the dees. The practical energy limit for cyclotrons is about 25 MeV for protons or deuterons.

SYNCHROCYCLOTRON

The mass of accelerated particles increases as their speed and their energy increase, according to the relativity theory of Albert Einstein. This effect in an accelerator such as the cyclotron is not significant in energy ranges up to about 20 MeV. However, as the accelerated particles begin to approach the speed of light, the effect becomes much more marked. The increasing mass slows down the stream of particles and causes it to be out of step with the oscillations of the high-frequency electric current. Unless the particles arrive at the gaps between electrodes at the appropriate time, they will be thrown off course.

In 1945, E. M. McMillan at the University of California and V. Veksler in the Soviet Union independently showed how one could keep accelerated particles in step with the applied electric field, despite the increase in mass. There would be two possible methods. In one, the magnetic field would be increased in proportion to the mass. In the other, the frequency of the oscillating current could be decreased as the mass of the particle increased. The magnetic field would be left unchanged. This second method was applied to the cyclotron. It resulted in the development of a modified cyclotron, called the *synchrocyclotron*.

In the synchrocyclotron the oscillations of the electric field are slowed down to match the increased mass and decreased speed of the particles. The particles continue to receive an energy boost each time they pass the gap between electrodes. The principle was first applied in 1946 to a 470-centimeter cyclotron at the University of California. This instrument had originally been planned as a giant standard cyclotron. A number of other synchrocyclotrons have been built, mostly in the energy range between 300 and 400 MeV. A high-energy machine operates at 680 MeV at the U.S.S.R. Academy of Sciences laboratory outside Moscow. The large synchrocyclotron at the University of California has been reconverted so as to produce an energy of 730 MeV.

The high-intensity beams of particles produced in the synchrocyclotron are of tremendous value in experimental research, as in the analysis of mesons. As beams emerge from the instrument, they can be led through channels in shielding walls to perform various experiments.

THE BETATRON

The particle accelerator called the *betatron* makes it possible to obtain streams of high-energy electrons by magnetic induction. "Betatron" comes from *beta particles,*

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This device, called a synchrocyclotron, is a modified cyclotron. It can accomodate the mass changes involved with particles traveling at relativistic speeds.

a name applied to electrons emitted in the form of rays. The betatron is based on the same principle as the electric transformer, in which an alternating current is applied to a primary coil and induces a similar current, with a higher or lower voltage, in a secondary coil. In the betatron, a changing magnetic field is used to accelerate electrons around an orbit. The first practical betatron was built by Donald W. Kerst at the University of Illinois in 1940.

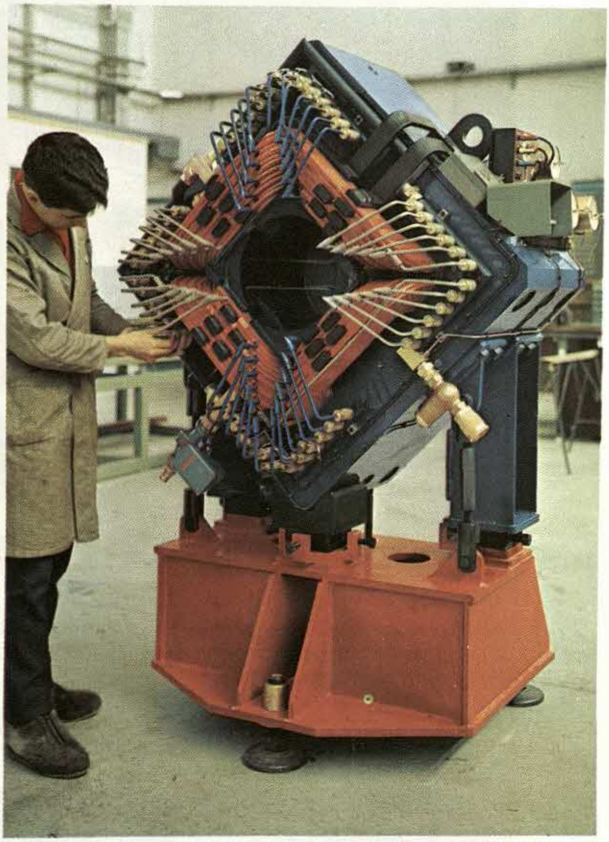
A ring-shaped vacuum chamber, called a *doughnut*, is placed between the poles of an electromagnet. Most of the magnetic flux passes through the doughnut hole. The magnetic field is reversed 60 times a second, each time increasing from zero strength to full strength. Electrons are produced from a heated filament. They are led into the doughnut just as the magnetic field at the orbit location starts to increase from zero strength. As the magnetic field grows, the electrons are accelerated. They follow a circular path of constant radius within the doughnut of the betatron.

The streaming electrons are then diverted from their circular path so as to strike a target at the edge of the chamber, or outside of it. High-energy X rays are produced from a target struck in this way. These X rays can be used for scientific experiments, for medical diagnosis and treatment, and for various industrial purposes. Most betatrons produce electrons of about 20 MeV energy; a few have been built for higher energies. The largest betatron, built by Kerst at the University of Illinois, produced 300 MeV electrons.

ELECTRON SYNCHROTRON

The electron synchrotron, like the betatron, accelerates electrons. However, it produces greater energies. The device has a doughnut, and a ring-shaped magnet. The magnetic field does not extend through the hole of the doughnut, as in the betatron.

At one or more places around the doughnut a radio-frequency electric circuit called a *cavity* is located. A high-frequency electric field is produced across the gap in this cavity to accelerate particles. Electrons with an energy of 50 to 100 kilovolts are emitted from an electron "gun" at the side of the chamber. Every time the electrons cross the gap they receive an energy boost. To keep the orbit of the circling electrons constant in radius, the strength of the magnetic field is increased as the particles gain energy.

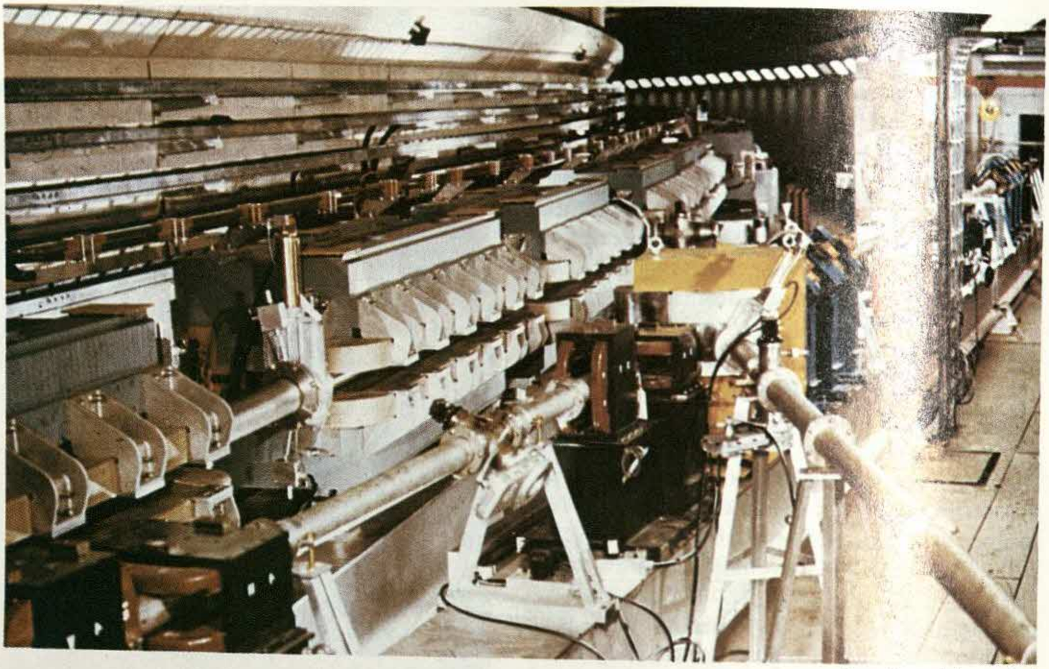


CERN

A large electromagnet used in a circular accelerator. Electromagnets cause the particles to accelerate outwardly in the form of a spiral until they pass out of the vacuum chamber.

At the end of the accelerating interval the beam is directed against a target, producing high-intensity X rays. In some installations, a beam of electrons is directed out of the chamber and is conducted away from it for other experiments.

In 1947 McMillan completed the first electron synchrotron of 300 MeV energy, though the principle had been demonstrated at lower energies before that time.



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An alternating gradient synchrotron. In this device, the particles are focused into a very narrow beam by strong forces that are produced by alternately converging and diverging magnetic fields.

A parallel development took place in the Soviet Union. Several electron synchrotrons have been built to operate at from 500 MeV to several GeV.

PROTON SYNCHROTRON

Another important type of synchronous accelerator is the proton synchrotron. This instrument smashes atoms in much the same way as electron synchrotrons. The difference is that in the case of protons, the frequency with which they complete their orbits increases constantly with increasing velocity throughout the acceleration period. Protons never quite reach the velocity of light. To match the increasing velocity of protons, the electric field providing acceleration is increased in frequency during the accelerating cycle. The magnet, different from that in older accelerators, consists of four *quadrants,* or quarter-circles, separated by four gaps.

The first two large proton synchrotrons were the *cosmotron* at Brookhaven National Laboratory on Long Island, New York, and the *bevatron* at the University of California. The cosmotron is so called because, operating at 3.0 GeV, it produces beams of protons with energies found hitherto only in cosmic rays. The bevatron is even more powerful. It operates at 6.2 GeV. The name "bevatron" comes from "*b*illion *e*lectron *v*olts," because it runs in that range. In both machines protons are injected into the orbit by an auxiliary accelerator. A Van de Graaff electrostatic generator is used for the preliminary speeding up of particles in the case of the cosmotron. A linear accelerator accelerates particles for the bevatron.

ALTERNATING GRADIENT PRINCIPLE

In 1952 a new principle of magnetic focusing—the *alternating gradient principle* —was proposed by E. Courant, M. S. Livingston, and H. Snyder at Brookhaven National Laboratory. This has led to a new class of magnetic accelerators, in which the pole faces are shaped to produce strong focusing forces by means of alternately converging and diverging magnetic fields. Protons (or electrons) in a vacuum chamber are focused into a very narrow beam, which permits using a vacuum chamber of comparatively small cross section. Smaller magnets can be used to keep the circling particles on course. It has also become practical to build magnetic accelerators of much larger orbital radius and much higher energy.

The first major devices using strong focusing were the proton synchrotron of 28 GeV at Geneva, Switzerland, and the alternating gradient synchrotron of 33 GeV at Brookhaven, Long Island. In the U.S.S.R., at Serpukhov, is a still larger accelerator of this general type, of 76 GeV. In Batavia, Illinois, an accelerator of 400 GeV was built, and in the same underground tunnel, a 1,000-GeV *tevatron* was tested in 1983. A proton accelerator, the tevatron uses 1,000 supercooled magnets to lower its energy needs.

OTHER ACCELERATORS

Powerful accelerators of other types have been built. Beams of particles can be made to collide head on instead of striking a stationary target. The energy of each beam thus adds to the effect of the collision.

The Super Proton Synchrotron at the European Organization for Nuclear Research (CERN) in Geneva, Switzerland, was converted to a proton-antiproton collider. In 1983 it was used to confirm the existence of the three intermediate vector bosons predicted to be the carriers of the weak force. CERN has under construction a 27-kilometer Large Electron-Positron storage ring (LEP) to collide electrons and positrons. At Serpukhov work has started on a superconducting accelerator several times more powerful than the tevatron. In the United States, proposals were made for a colliding beam accelerator of 20,000 GeV with a circumference as large as 160 kilometers.

In this linear accelerator, or linac, a high-frequency oscillating electric field causes the electrodes to change their electric charge, thus attracting and accelerating the atomic particles through the main cylindrical tube.

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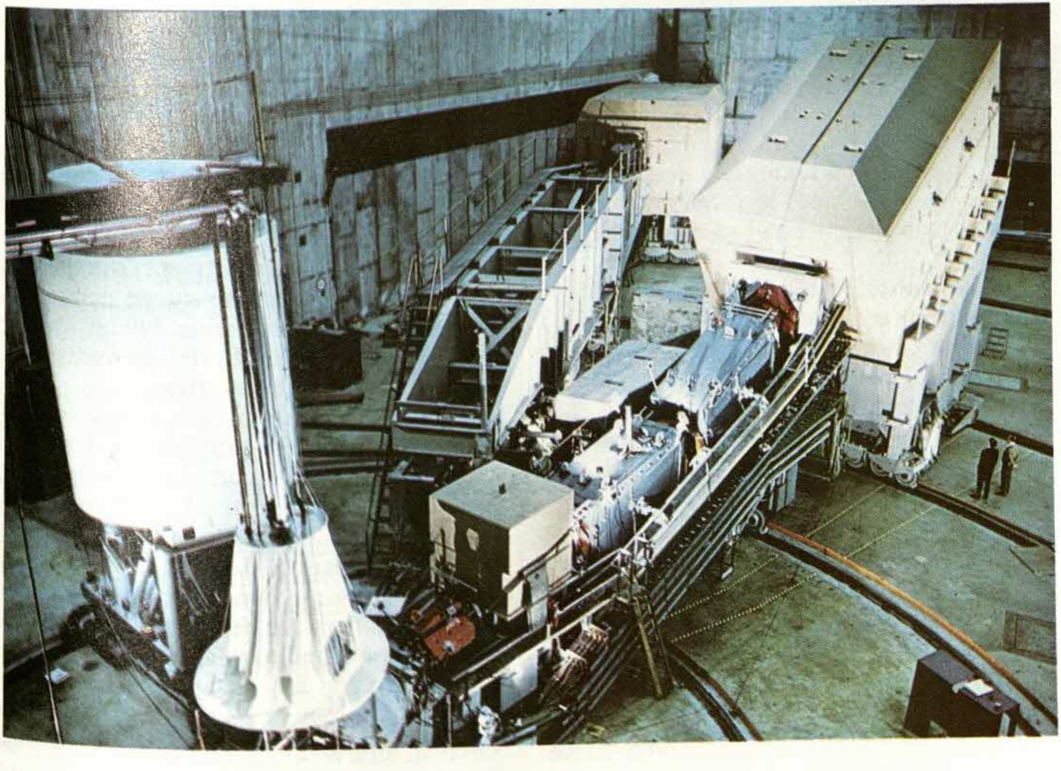
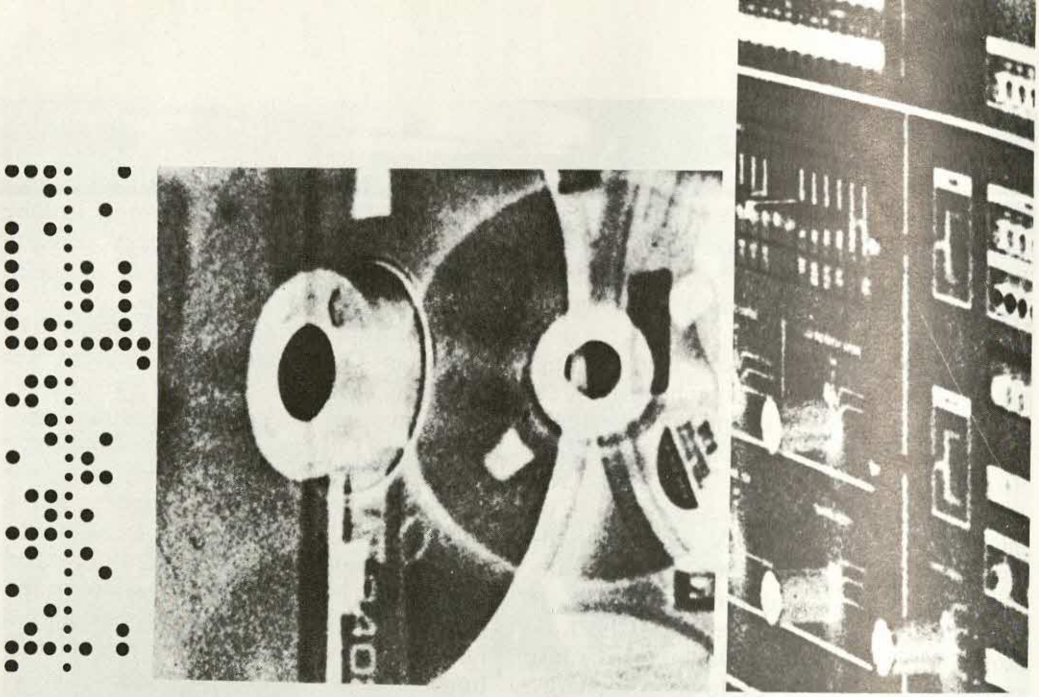




The Science Teacher

AUTOMATION AND ROBOTICS

When a person puts a load of dirty clothes in the washing machine, turns it on, and comes back later to find clean clothes that have been washed, rinsed, and spin-dried, that person is taking advantage of *automation*—a machine has taken over a chore that in the past had to be done by a human.

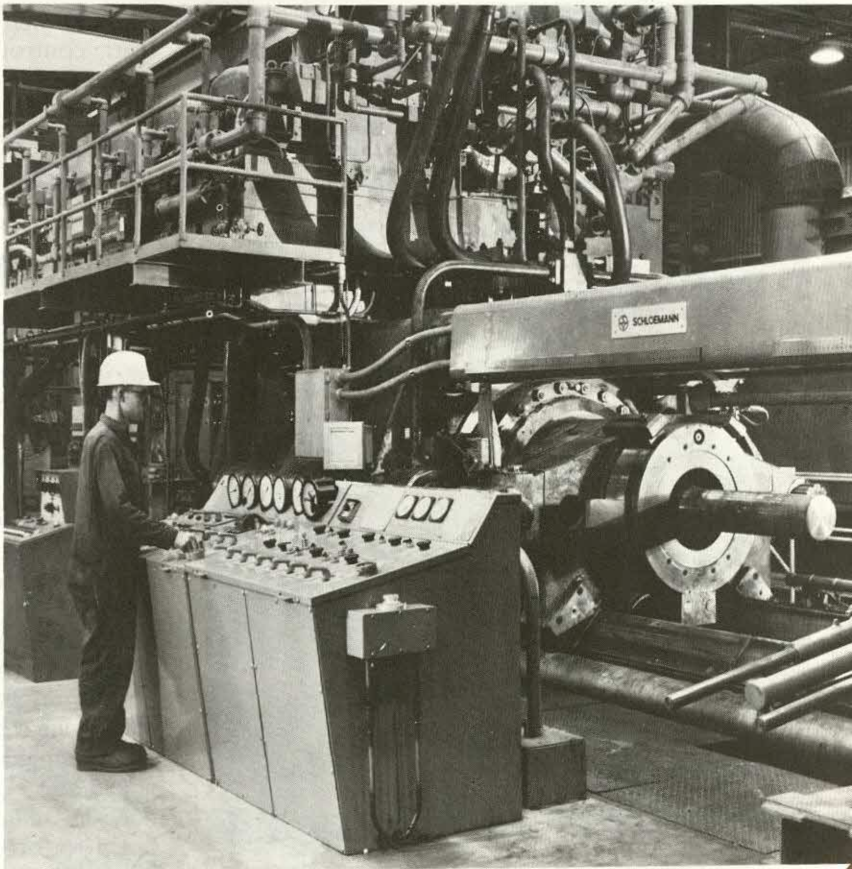
Automation has become part of so many aspects of our daily lives that we generally don't notice it—except when something breaks down. Self-service elevators, central heating and air conditioning, the direct-dial telephone system—all involve automation. Furthermore, nearly all the goods we use, from the foods we eat to the cars we ride in, are products of automation.

The greatest use of automation has been in industry, where it has brought about faster and cheaper mass production of goods. With the use of computers, even the cutting of complicated, high-precision parts is now done by self-regulating machines in one smooth and rapid operation. The process no longer has to be interrupted to measure the work, compare it with specifications, reject errors, and make necessary adjustments. Automatic controls perform all of these tasks continuously.

Automation is important in many offices, as well as in factories. Banks, insurance companies, department stores, and many other businesses rely on computers for such jobs as accounting, billing, and inventory. In the field of printing, computers are being used for typesetting.

The use of automation is now spreading to new fields. For example, modern hospitals have complex automatic monitoring equipment that keeps track of the patient's vital functions. New automated techniques for the diagnosis of disease are also being developed. For example, computers and other equipment are being used to diagnose heart ailments and to read X rays.

One of the largest applications of automated equipment is in the communications industry. Automatic switching



Factory automation has greatly reduced the numbers of workers required to perform a wide variety of operations. Here an engineer stands in front of a control panel of a very large brass rod extrusion press.

Chase Brass and Copper Co.

devices have saved thousands of man-hours and made possible millions of dollars in cost savings. The effect on U.S. labor was made dramatically visible in the summer of 1983 when a strike by telephone workers had little impact on service.

SELF-REGULATING MACHINES

Automation, in the sense of mechanization, has been going on since primitive man began using tools to simplify his labors. However, large-scale automation did not really have its beginnings until the Industrial Revolution of the 1700's. Automation in the technical sense of the term is almost completely a product of the 20th century.

One of the first self-regulating machines—one with an automatic control system—was designed by the Scots engineer and inventor James Watt. In 1787 Watt designed a *governor* to control the speed of his steam engine.

Known as the *centrifugal,* or *flyball, governor,* this device was geared to the engine by a belt and pulley. It consisted of a vertical shaft on which two arms were crisscrossed, as in a pair of scissors. The arms were weighted at their lower ends. As the engine speed increased, the spinning arms were flung outward. In this outward position they operated a linkage that, in turn, automatically reduced the supply of steam to the engine. This caused the engine to slow down. As the engine slowed down, the reduced outward force allowed the arms to drop. This increased the steam supply and caused the engine to speed up once more. In this way the engine could be made to run automatically at a more or less constant speed. This type of governor, with minor modifications, is still in use.

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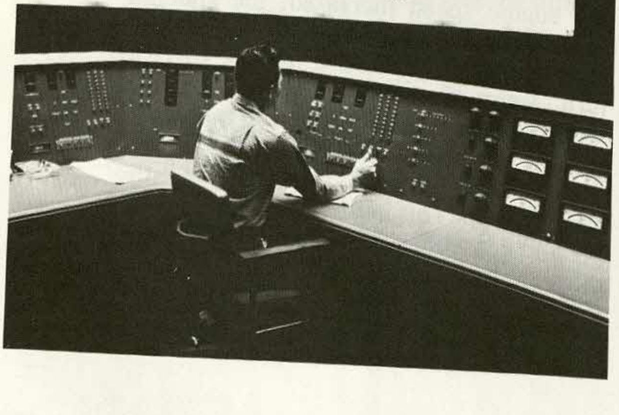
Automation on a small and large scale. Above: an electronic scanner grocery checkout device. Below: a single person operates a gas-dispatching room of a pipeline system. Pipeline conditions can be read off of the display board.

Columbia Gas System



Another major development in automatic control systems was the invention of a *steering motor* by the British engineer Isambard K. Brunel. This steering motor was used to turn the heavy rudders of oceangoing steamships. A device of this kind was installed on Brunel's ship the *Great Eastern*, which was launched in 1858.

In Brunel's steering motor, an inlet valve admitting steam to a cylinder was opened by turning the helmsman's wheel. An ingenious *follow-up linkage* constantly compared the angle of the rudder with the angle of the wheel, and closed off the steam as the rudder swung around to the desired position.

This early steering motor was the prototype of the modern *servomotors*. These devices are "enslaved" motors that use the principle of feedback to supply varying amounts of power according to the demands of a controlling mechanism.

From its beginnings automation has undergone a rapid evolution. The first automatic machines could do a single, predetermined job. Later, with increasing sophistication, machines were developed that could perform a sequence of jobs, be run by remote control, measure the quality of the product, and make corrections for any error found in the product.

In the most highly developed automatic control systems, possible errors are corrected during the operation. In some, such as spacecraft systems, information from the environment is constantly evaluated, and the possible errors are corrected even before the operation is carried out.

THE SCIENCE OF CYBERNETICS

The application and general analysis of control systems in both living organisms and machines is known as *cybernetics*. The word was coined in 1948 by the American mathematician Norbert Wiener from the Greek word meaning "steersman." In the broadest sense, cybernetics is the science of the control of systems. More specifically, cybernetics is concerned with systems that are able to regulate their own operations without human control.

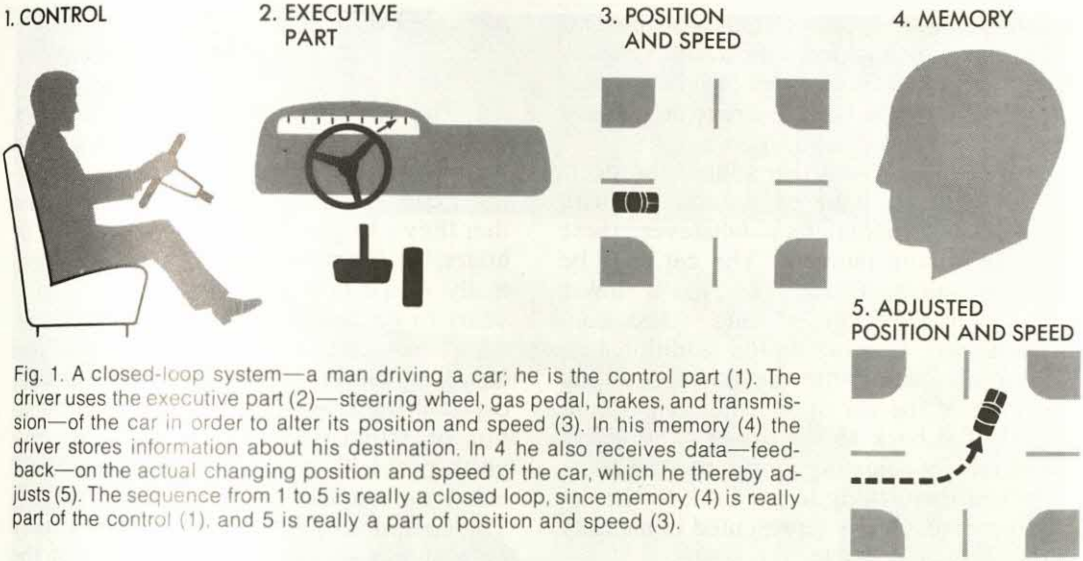


Fig. 1. A closed-loop system—a man driving a car; he is the control part (1). The driver uses the executive part (2)—steering wheel, gas pedal, brakes, and transmission—of the car in order to alter its position and speed (3). In his memory (4) the driver stores information about his destination. In 4 he also receives data—feedback—on the actual changing position and speed of the car, which he thereby adjusts (5). The sequence from 1 to 5 is really a closed loop, since memory (4) is really part of the control (1), and 5 is really a part of position and speed (3).

FEEDBACK

This automatic regulation is done by using *feedback;* information about the end product that is fed back to a regulating device, causing it to modify or correct production procedures if necessary. If a control system is to be considered automated in a technical sense, a feedback mechanism must be present within it.

Perhaps the concept of feedback is best explained by using a familiar example: When a person drives a car, he or she is concerned with two things: its speed and its position with respect to the road and other cars. The driver controls the speed and position of the car by means of the steering wheel, the brakes, the accelerator pedal, and, if need be, the transmission. The driver keeps on the proper side of the road and corrects the car's velocity and position with respect to the road and the traffic situation. If necessary, the driver may even make a detour or respond to an emergency. The information that comes to the driver about speed and position and that makes further management of the car possible is one kind of feedback.

If the car and driver are regarded as a single unit instead of as two separate things, they constitute a self-regulating system. In cybernetic language, the driver is the controlling part of the system, directing the movements of the entire car-person unit through the *executive* part of the system: steering wheel, gas pedal, brakes, and transmission. These in turn affect the power and motive mechanism of the auto: the engine and the wheels.

The driver must maintain a proper position on the road and in relation to other cars. In other words, the driver has *information* about the destination, position, desired speed, and desired positions. This information is stored in the driver's *memory,* or, in cybernetic terms, in a *data-storage bank.*

How did the information reach the driver? That is, how was the driver programmed? The decision to take the trip may have been a personal one or may have been made by someone in authority. The same may be said of the decision to make the journey by car. At an earlier time, of course, the driver had been taught to drive. That is, information on how to drive and how to obey traffic rules was programmed into the driver by other people.

With all this "data" in his or her "memory bank," the driver directs the auto, regulating the position and speed of the vehicle. The position and speed are controllable factors called *parameters*. These may deviate from the desired parameters because of a number of other things: other cars, the fact that the road curves and goes up and down, and so on.

Therefore, the driver adjusts the steering and speed of the car to conform with the desired parameters—whatever these may be at the moment. The car may be guided "out of its way" to pass a slower vehicle or even turned onto a less congested road. In other words, additional information about the actual speed and position of the car at any moment is constantly fed back to the driver. The driver responds by adjusting the auto to the situation and then trying to get back to the desired parameters as represented in memory as quickly as possible.

The concept of feedback is at the very heart of cybernetics. It is what makes a system automatic and self-regulating. Briefly defined, feedback is information about the actual state of a system and is used by the controlling part of the system to bring itself to a desired state that has been programmed into it. Such a feedback-based system is called a *closed-loop system* because the activity occurs repeatedly in a continuous cycle. The car-person system described above is a closed-loop system.

APPLICATIONS

The applications of cybernetics are growing very fast and already have accomplished wonders. Engineers have developed calculating devices that work so fast that they can perform, in a few minutes or hours, mathematical operations that normally would take a group of people many years to complete. In the field of science, computers construct models of situations based on the ideas and mathematical concepts of the researchers. This is a simulation of actual or possible conditions in a given problem. Years of tedious trial-and-error experimentation are thus avoided. The computer displays the results visually on a screen or provides a printout of the theoretical results.

In engineering and technology, similar computer methods are employed. An architect, for example, can use a computer to design a building and can make changes in the design that is shown on the display screen of the computer.

Computers are coming into wider use in medical diagnosis. Symptoms of many diseases of a given organ or body system are stored as data in the memory bank of a computer. When confronted with the symp-

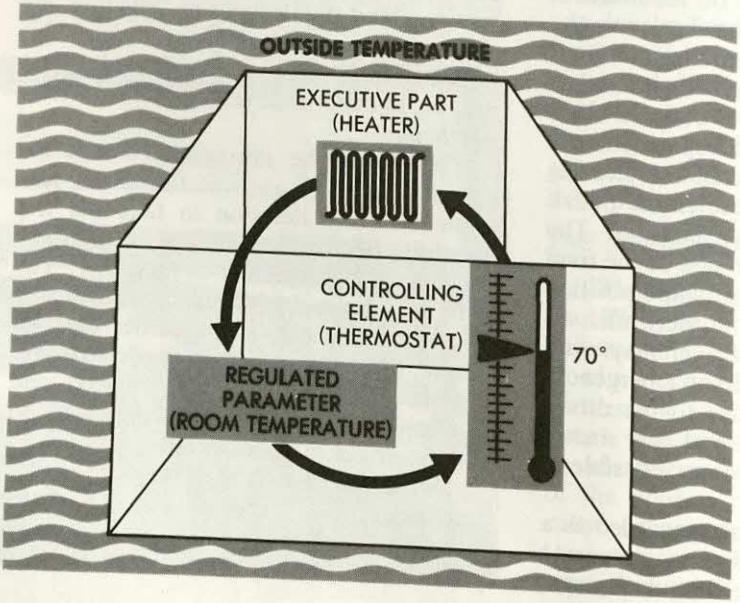
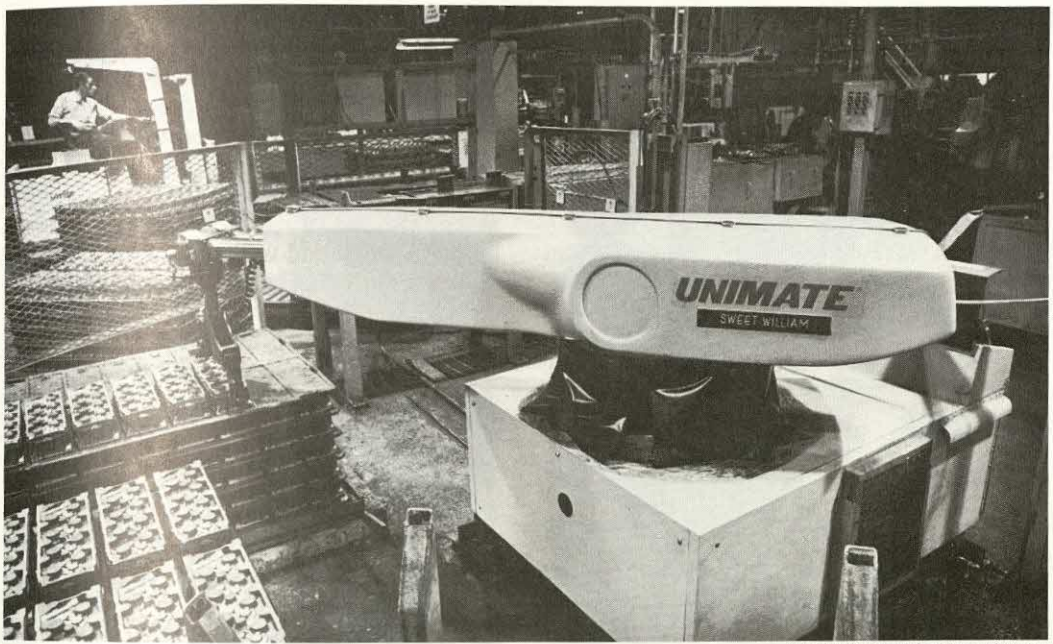


Fig. 2. A completely automatic closed-loop system—a thermostat controlling a room's temperature. The controlling element is a thermometric device that can be set at any desired temperature reading. It controls the heater—the executive part. Actual room temperature is the regulated parameter. The heater keeps operating as long as the room temperature is below the desired reading of 25° Celsius. Once the latter is reached, the thermostat turns the heater off. When room temperature drops below the set reading, the thermostat switches the heater on again. The outside temperature affects the room temperature.



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This industrial robot works in an automobile plant, where it is programmed to move heavy engine blocks from stacks to the assembly line.

toms of a patient, the doctor feeds them into the computer, which provides the proper diagnosis of the disease by comparing the symptoms with those already in its memory. This has already been done for diseases of the cornea (part of the eye) and the heart, for example. Also, actual working models of the heart and lungs can keep a patient alive during a surgical operation on his corresponding organs.

Cybernetics is being fruitfully applied to the social sciences—sociology, economics, politics, linguistics, and education. Cybernetic analysis clarifies many complex situations in these areas, enabling sociologists and other experts to predict many social processes. Models are also constructed with computers, much as in science and technology.

Teaching machines use cybernetic principles to instruct students on an individual basis. Computers have been made to translate languages and even edit and write stories and poetry. Through cybernetic analysis, language experts have found that most languages have over 50 percent redundancy. This is, if you remove, at random, 50 percent of the letters of a text, it can still be understood.

INFORMATION AND COMMUNICATION

In its broadest meaning, information is anything that tells something to someone or to some other thing. Significant information changes the state of the system it enters. Going back to the auto and its human driver, we may say that the latter transmits information to, or communicates with, the mechanical parts of the car—steering, brakes, gas pedal, transmission, and so on. We usually think of information transmission, however, as taking place between two intelligent beings, or persons, either directly through speech or through some mechanical medium, such as telephone, radio, or writing.

Actually, such conscious, intelligent communication is only one example of communication in general. The gap between the living and the mechanical is being narrowed by continuous developments in the cybernetics, information, and

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Above, a designer provides specifications to a computer that plans printed circuit boards. Below, a computer drawing of a new commercial jetliner.

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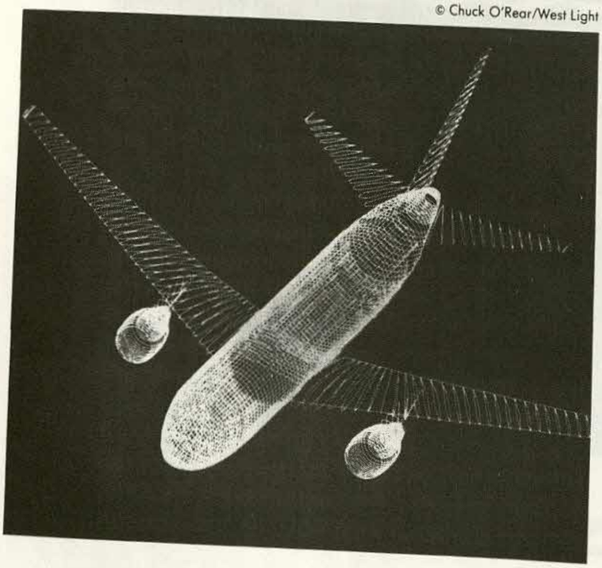


communication fields. Biological activities, even thinking, may to a large extent be explained in cybernetic terms. Machines, especially computers, are becoming more intelligent and lifelike, seemingly, in their behavior.

Just how does communication take place? On one of its most complex levels—human speech and writing—communication makes use of *languages* and *symbols,* or *signs* (letters and numbers), which are variously combined to make *messages*. Messages must be transmitted by some kind of physical action—biological or mechanical—such as speech, writing, gestures, telephone, television, telegraph, or radio.

In other words, messages are conveyed by *signals* of some kind. In electrical communication, the message is converted into pulses that are finally impressed on electromagnetic waves. At the receiving end, the electrical signals are changed back into recognizable sounds or perhaps writing.

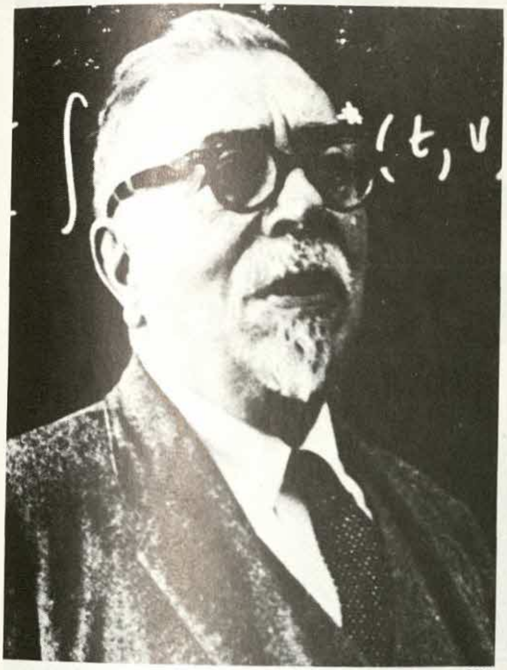
A comprehensible system of definite signals, along with the symbols (letters, numerals, and other signs) that they represent, makes up a *code*. The most familiar example perhaps is one of the Morse codes in telegraphy, where each letter and number is represented by pulses of electricity called "dots" and "dashes."

Another encoding system is *binary notation,* used in computers. Each number or letter is represented by particular combinations of ones and zeros, or, electrically, by "on" and "off" switch positions. A binary numeral, or digit, abbreviated *bit,* thus represents a certain minimal amount of information.

Let us now take some of these ideas about communication and information and apply them to the cybernetic system described earlier in the article.

CYBERNETIC COMMUNICATION

Information of all kinds comes into and passes through a cybernetic system. Visual and auditory signals about the state of the road and traffic enter as light waves and sound waves into the eyes and ears, respectively, of the driver. They influence the



UPI

Dr. Norbet Wiener coined the word cybernetics. Cybernetics comes from the Greek word meaning pilot or governor.

driver's actions. The driver sends orders to the executive system of the car by pushing down or easing off the gas pedal, by pressing or releasing the brake pedal, and by turning the steering wheel in a suitable direction.

These driver actions on the executive system of the car may be said to constitute signals. The car also signals the driver by the way it reacts to his orders.

The executive system communicates the driver's signals to the power plant and wheels of the car by a system of linkages. When the driver, for example, pushes down on the brake pedal, a set of devices transmits the pressure to the brake mounted on each wheel of the auto. This action slows down the car.

At any point in the cybernetic and communication processes, we notice that one kind of signal may be transformed into another. In a radio transmitter, for example, the air waves generated by a person's speaking are transformed into electromagnetic waves. At the receiving station, the electromagnetic waves are transformed back into air vibrations. As the air vibrations hit the ears of the listener, they are transformed into nerve impulses and then are transformed into intelligible words in the listener's brain.

The ability of a machine to "communicate" with another machine and to be "programmed" by a human is the basis of automation. Automated machines can be found in the home (thermostat, automatic coffee maker, dishwasher) as well as in industry.

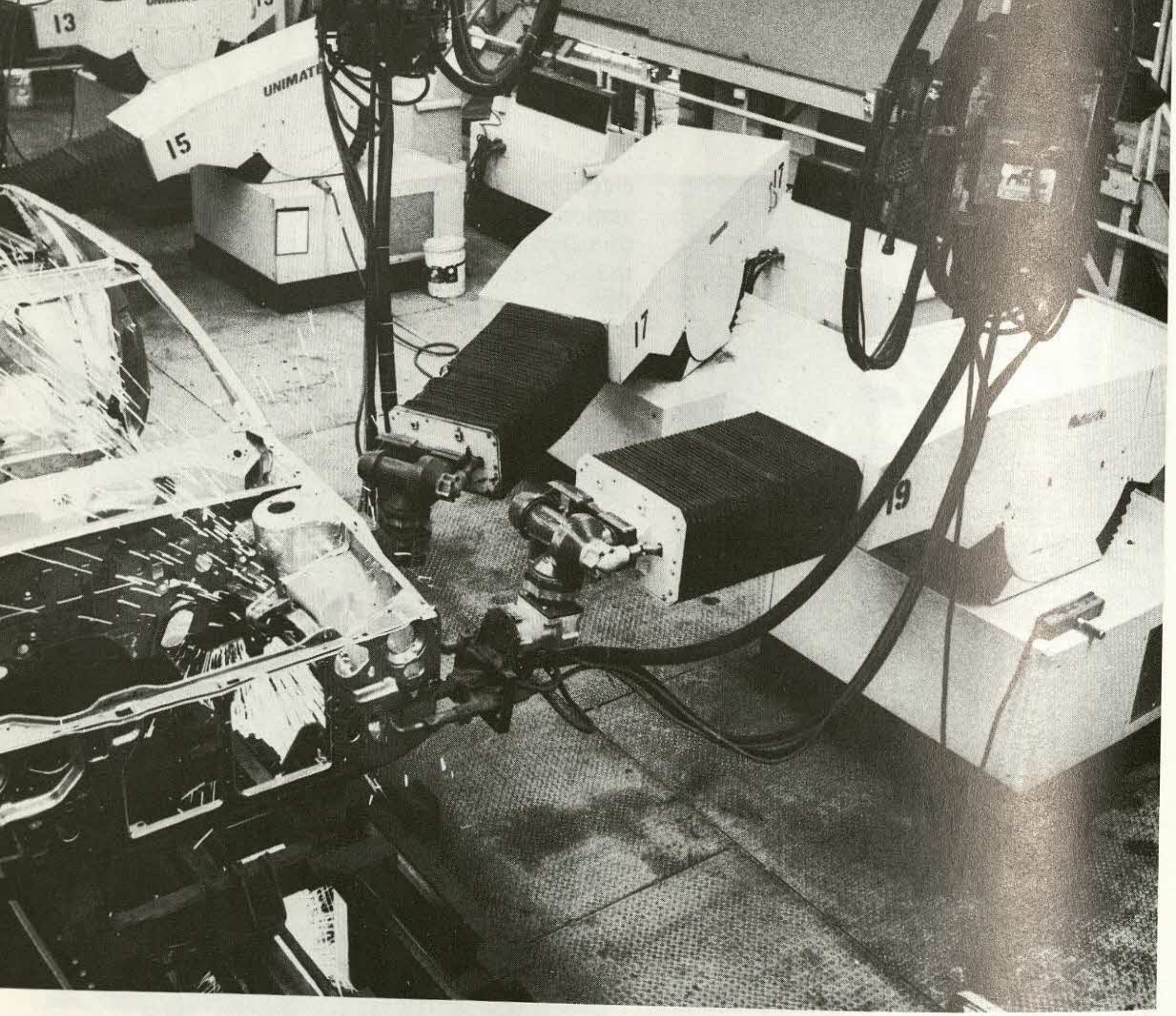
AUTOMATION IN INDUSTRY

Some industrial operations lend themselves more readily to automation than others do. Automation is most readily and economically applied to the large-scale production of a single article. For example, the manufacture of machine parts and the production of certain foods are both highly automated. On the other hand, industries where the demand is subject to wide seasonal variation or where there are frequent design changes are unlikely to be automated.

In some industries a break in the flow of production can ruin the product. Here automatic controls are valuable. For example, chemical and petroleum plants are now almost completely automatic, from the injection of crude materials, through the processing reactions, to the final packaging for shipment. The chemical concentrations, heat, and pressure throughout the processes are too extreme and require too much constant testing and adjustment for human control. Meters and feedback control systems have solved the problem.

Companies involved in the use and manufacture of toxic chemicals have developed fully automated production lines. Computers monitor the accurate flow of all chemicals, assure that proper heat and cooling exists in all parts of the "line," and control the final delivery of both active chemicals and waste products to their proper destinations.

In petroleum refineries, highly sophisticated automatic control systems actually



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Industrial robots perform dangerous or boring jobs in a tireless and consistent manner. These assembly line robots are making automobile body welds.

make possible the production of modern high-quality fuel. Without automation, the rate of production and the quality of the product would both be drastically reduced.

In these plants a small group of engineers is still required for monitoring the operation from a central control room. The end product is tested in a separate laboratory, and the results are sent back to the engineers for necessary correction in the process. New methods of continuous end-product analysis are making more and more plant operations entirely automatic.

Automatic controls are indispensable in atomic energy production. People cannot work too close to nuclear reactors because of the dangerous radiation that accompanies the splitting of atoms. Automatic regulation also averts the possibility of a disastrous explosion that might be caused by a slight error in human judgment or by the slowness of many human reactions. Nuclear power generating stations have become so heavily automated that in 1983 the major cause of plant shutdown was not improper handling of atomic materials but the malfunctioning of automated fail-safe systems.

In 1983 Japan's Yamazaki Machinery Works opened a "factory of the future" in Florence, Kentucky. The facility is designed to produce modern machine-tool parts. It is one of the world's first fully automated factories. Only six human workers are employed to tend the computers, assure that the various robots used in the manufacturing process are in good repair, and answer the phones.

ROBOTS

In science-fiction stories there are often robots with human or superhuman capabilities. These fictional computer-brained machines are portrayed as running factories, doing the household chores, producing more of themselves, and even as having human feelings. Perhaps future technologies will produce such machines, but at present they do not physically exist. However, mathematical models and theories of such devices do exist.

The word *robot* was coined in 1920 by the Czech playwright Karel Čapek. In his play *R.U.R.* (the initials of Rossum's Universal Robots—from the Czech word *robota,* meaning "drudgery"), Čapek portrays a society in which chemically constructed automatons operate all the factories. Thus, humans can "perfect themselves free from the degradation of labor." Robotics is the field concerned with the design, development, and maintenance of robots.

Many people think of robots as mechanical people that can see, feel, walk, and talk much like the *Star Wars'* robots C3PO and R2D2. The robots in use today, however, are not lifelike copies of men and women but industrial machines designed to perform one or more simple and repetitious tasks, such as spot-welding automobile bodies, spray-painting a metal part, or tending die-casting machines. Industrial robots also perform a wide variety of materials-handling tasks.

Basically, an industrial robot is a machine that can be programmed to do a variety of tasks that are usually done by human factory workers. Like their human counterparts, industrial robots can be switched from one job to another and can be "taught" (programmed) to handle new tasks. Robots can shear sheep, pluck chickens, sort vegetables, and assemble mechanical components.

Unlike humans, robots can work 24 hours a day, seven days a week, without taking a coffee break, sick leave, or vacation, and without becoming directly involved in a labor-management dispute. Robots accomplish their tasks with great precision and with a low error rate. Unlike humans, they are relatively insensitive to excessive heat, cold, dust, radiation, and toxic chemicals.

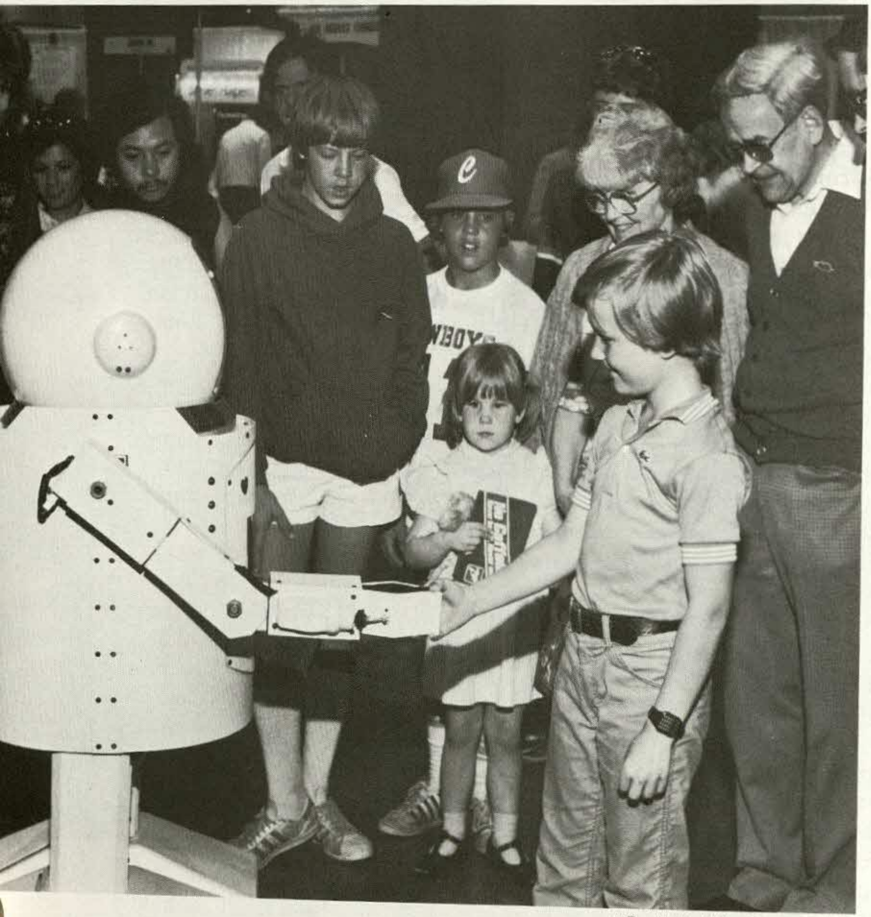
When a human worker welds a seam, he cannot keep his torch on the work for more than 30 percent of the time because of the intense heat and glare of the welding arc. A robot welder can keep its torch on the workpiece about three times as long. Although the robot cannot work any faster than the human, it can thus produce about three times as much work.

Although robots effectively accomplish simple mechanical tasks, they cannot as yet compete with fixed, self-operating machinery that is designed to perform repetitive operations in the assembly of mass-produced components. An automated bottle-capping machine, for example, can cap and seal several dozen bottles a second. Robots are still too slow and expensive to be cost-effective in such automated assembly situations. Also, both experiments and on-the-job testing have shown that robots do not compete successfully with human workers in batch or small-lot assembly operations.

LEARNED SKILLS AND NEW ROLES

The microcomputer, the heart and brain of an industrial robot's sensory system, is becoming more sophisticated and less expensive with each passing year. By the end of the 1980's, it is expected that fast, accurate, multidexterous industrial robots will respond to a wide variety of sensory cues, to "learn" by trial and error, and to acquire skills by analyzing and solving specific work problems. Such "learned" skills could conceivably be transferred to other robots.

The American Society of Manufacturing Engineers (ASME) has stated that by 1990 sensory techniques will permit robots to approximate human capability in assembly and that at least 15 percent of all U.S. assembly systems will use robotic technology. The ASME estimates further that 20 percent of the labor involved in automobile assembly and half of the labor in small-



Android robots are popular as educational devices to introduce people to the expanding field of robotics.

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component assembly will be replaced by some form of automation.

Before the mid-1990's, robots are expected to branch from basic assembly operations to such areas as the construction trades. Robots will carry building materials, position panels, lay stone and brick, and cut lumber to size. In inhospitable environments, such as outer space and the ocean floor, robots will be engaged in construction and mining operations. In the future, automated factories could perform most, if not all, manufacturing and assembly operations now performed by humans. The ultimate factory will see robots reproducing themselves. Automated factories will manufacture machines for other automated factories.

One of the largest users of robots will be the military. A report issued in 1982 by the U.S. Army's War College Strategic Studies Institute noted that "robots enhanced with sensors and with artificial intelligence—computer programming that enables them to 'think'—would be able to take over routine or dangerous jobs of soldiers, or even do things soldiers cannot do."

The Army's report suggests that by the next century smart robots may be enlisted to load weapons and handle ammunition, detect enemy minefields, implant devices capable of identifying and reporting enemy movements, and identify, track, select, and destroy enemy air or ground targets. They may also handle such routine battlefield tasks as digging, filling craters, building obstacles, and transporting supplies. Robots could handle hazardous or contaminated materials as well.

SOCIAL EFFECTS OF AUTOMATION

The introduction of automation has had widespread effects on the economics and labor forces of the industrialized nations of the world. It is estimated that approximately 25,000 robots were employed in the world's factories at the end of 1983, with some 14,000 in Japan, 6,000 in the United States, and the remainder in Europe. Predictions are that by the end of the decade the number in the United States will climb to between 20,000 and 60,000 and in Japan to more than ten times those numbers.

Those who believe that the increased use of robotics and automation will not cause widespread unemployment claim that robots and other new technologies lead to promotions and reassignments, not replacement. They point out that many new job opportunities have been made available to former assembly personnel, including new positions in technical maintenance and computer programming. The robotics industry itself, for example, grew from two manufacturers in 1972 to more than a dozen a decade later.

Labor unions generally oppose the introduction of labor-saving devices unless there is some assurance that jobs will not be lost. If a high degree of job security is felt by the workers, robots and other new technology are introduced smoothly. However, many spokesmen for workers in the auto industry in particular feel that robots will increasingly displace human beings on the assembly lines. They cite robotics, computer control, and other computer applications as well as worldwide standardization of auto parts as examples of advanced technology that will have serious social consequences.

Mass production through automation has made available a wide range of relatively inexpensive consumer goods of uniform quality. For the worker, shorter workweeks have, here and there, been made possible through automation.

In terms of actual working conditions, automation has generally had a beneficial effect. Heavy and dangerous work is now done automatically in many countries. Factories are generally safer and cleaner. Workers suffer less exposure to hazardous operations and irritating substances.

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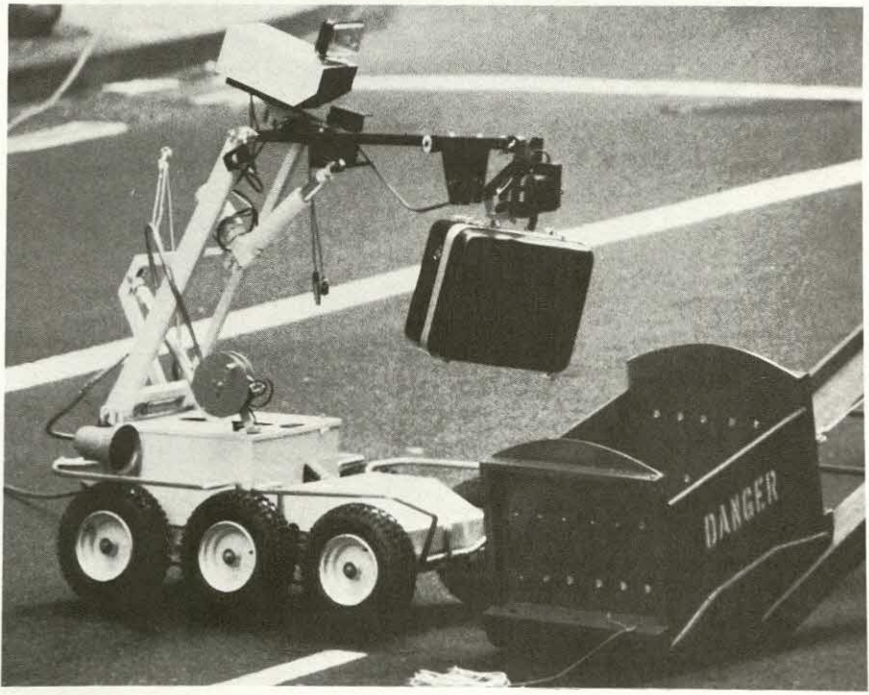
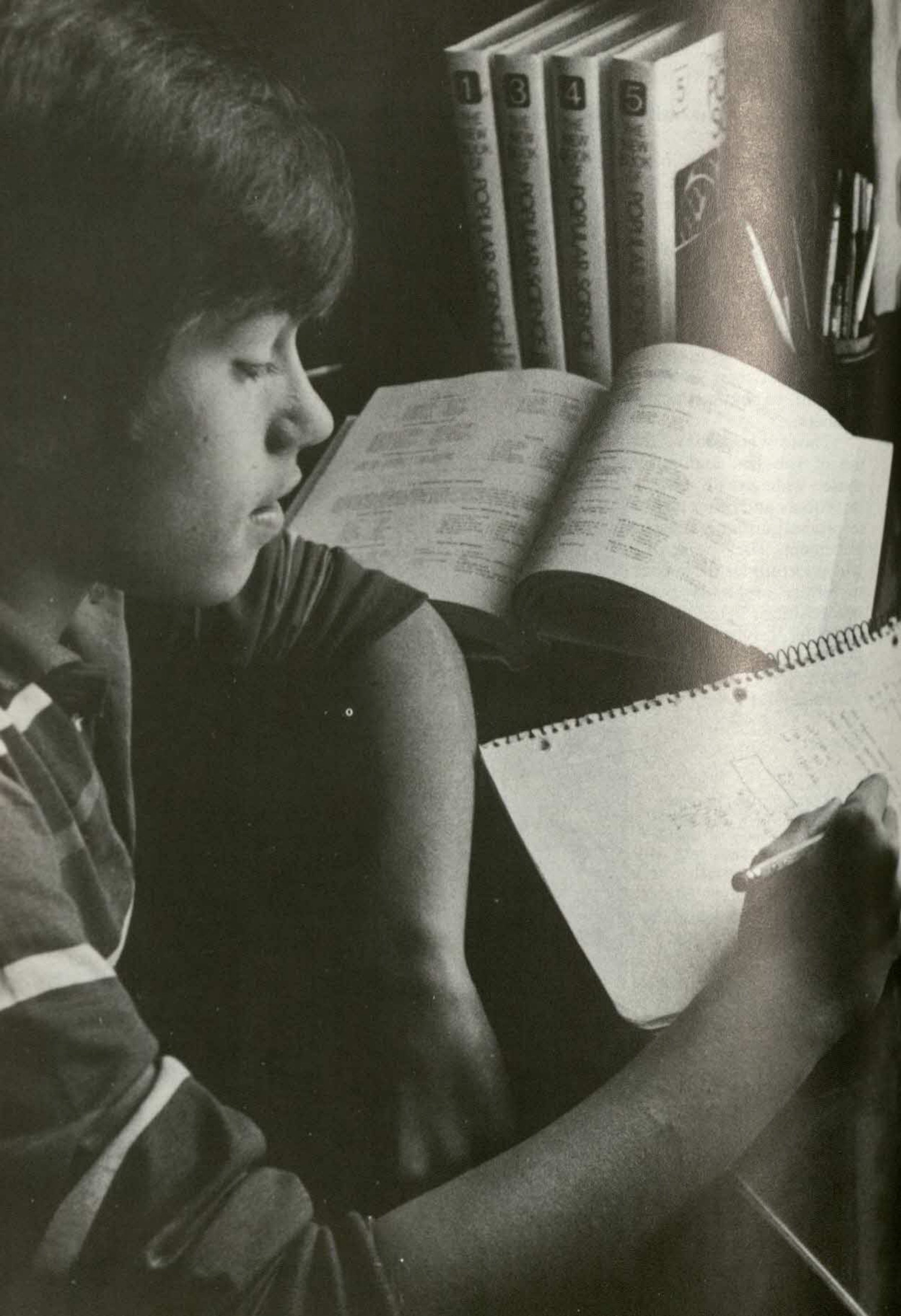


A risk-taking robot operated by the New York City bomb squad maneuvers a suspicious attache case into a cradle for safe disposal.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POPULAR SCIENCE

APPENDIX

380 Selected Readings
383 Nobel Prize Winners in Science
391 Mathematical Symbols
391 Important Constants for the Physical Sciences
392 Units and Symbols
393 Comparison of Temperature Scales
393 The Metric System
394 U.S. Weights and Measures
395 Common Conversion Factors
396 Lengths, Areas, and Volumes

Above: General Electric
Left: Jan Braunle

The world of science is always growing. We can learn a great deal if we use the right tools and ask the right questions. In this appendix you will find many useful tables, charts, and constants. You will also find a list of readings which will help you learn more about the topics discussed in this volume.

selected readings

TECHNOLOGY

HISTORY AND GENERAL

Baldwin, Gordon C. *Inventors and Inventions of the Ancient World.* New York: Four Winds, 1973; 251 pp., illus.—Well-told story of the inventions that led humans from a hunting to an urban life; a good reference work for grades 7–12.

Birdsall, Derek, and Carlo M. Cipolla. *The Technology of Man: A Visual History.* New York: Holt, Rinehart & Winston, 1980; 271 pp., illus.—Well-chosen and handsomely presented record of artifacts from the most ancient pebble tools to the latest instruments of space exploration.

Briggs, Asa. *The Power of Steam.* University of Chicago Press, 1983; 208 pp., illus.—An illustrated history of the discoveries and challenges of the steam age.

Burstall, Aubrey F. *Simple Working Models of Historic Machines.* Cambridge, Mass.: MIT Press, 1975; 80 pp., illus.—Instructions for easy-to-build models from the past, such as Leonardo da Vinci's lathe and a Greek puppet theater mechanism.

Conot, Robert. *A Streak of Luck.* New York: Seaview/Simon & Schuster, 1979; 565 pp.—The title refers to a quote from the book's subject, Thomas Edison, given a perceptive and illuminating study here.

Day, John. *Engines: The Search for Power.* New York: St. Martin's, 1980; 256 pp., illus.—Lucid explanations of the workings of a wide range of engines, ancient and modern; profusely illustrated.

Feldman, Anthony, and Peter Ford. *Scientists & Inventors.* New York: Facts on File, 1979; 336 pp., illus.—Short sketches of the lives and accomplishments of renowned scientists and engineers, with excellent illustrations; for students and young adults.

Gibbs-Smith, Marvin, Charles Rees, and Gareth Rees. *The Inventions of Leonardo Da Vinci.* New York: Scribners, 1978; 110 pp., illus.—Uses Da Vinci's drawings, including some working models, to illustrate his depth of scientific interest.

Harpur, Patrick, ed. *The Timetable of Technology.* New York: Hearst Books, 1982; 240 pp., illus.—Timetables in chart form and articles on 20th-century technological achievements.

Herner, Saul, with Gene P. Allen and Nancy D. Wright. *A Brief Guide to Sources of Scientific and Technical Information.* Information Resources Press, 2d ed., 1980; 160 pp.—Concise and very selective guide for the engineer or scientist.

Kivenson, Gilbert. *The Art and Science of Inventing.* New York: Van Nostrand Reinhold, 1977; 195 pp.—Provides guidance in the process of inventing and the obtaining of patents.

Lodewijk, T., et al. *The Way Things Work: An Illustrated Encyclopedia of Technology.* New York: Simon & Schuster, 1973; 288 pp., illus.—A special edition for readers in grades 7–12.

Modern Scientists and Engineers. New York: McGraw-Hill, 3 vols., 1980—Revision of an earlier work, updating one-quarter of its 1,100 biographies of living and deceased scientists and engineers.

Pawlicki, T. B. *How to Build a Flying Saucer and Other Proposals in Speculative Engineering.* Englewood Cliffs, N.J.: Prentice-Hall, 1980; 176 pp.—Popular essays on how the Pyramids were built, the transmutation of elements, and the philosophy of other scientific advances.

Rowland, K. T. *Eighteenth Century Inventions.* New York: Barnes & Noble, 1974; 160 pp., illus.—A reference book with bibliographies, providing a look at the beginnings of the Industrial Revolution.

The Smithsonian Book of Invention. New York: Norton, 1978; 256 pp., illus.—The history of invention, with examples of inventions in many fields.

Strandh, Sigvard. *A History of the Machine.* New York: A & W Publishers, 1980; 240 pp., illus.—The history of machines, in readable text with attractive illustrations.

Williams, Trevor I. *A Short History of Twentieth-Century Technology.* New York: Oxford University Press, 1982; 411 pp., illus.—The way that modern technology developed.

TRANSPORTATION

Allen, G. Freeman. *The Fastest Trains in the World.* New York: Scribners, 1979; 160 pp., illus.—A unique approach to railroading, concentrating only on the high-speed trains of the world.

Aylesworth, Thomas G. *Cars, Boats, Trains and Planes of Today and Tomorrow.* New York: Walker, 1975; 115 pp., illus. —A concise survey of several possible developments in transportation, from sea to outer space; for grades 6–9.

Botting, Douglas. *Shadow in the Clouds: The Story of Airships.* Baltimore: Penguin Books, 1975; 48 pp., illus.—The history and potential for lighter-than-air craft; for grade 5 and up.

Cudahy, Brian J. *Under the Sidewalks of New York: The Story of the Greatest Subway System in the World.* Brattleboro, Vt.: Stephen Greene Press, 1979; 176 pp., illus.—Treats the subject thoroughly, historically, technically, and politically.

Dark, Harris Edward. *Auto Engines of Tomorrow: Power Alternatives for Cars to Come.* Bloomington: Indiana University Press, 1975; 180 pp., illus.—Review of some of the work now going on in this field.

Gibbs, Tony. *Navigation: Finding Your Way on Sea and Land.* New York: Franklin Watts, 1975; 88 pp., illus.—A good beginning text, mainly on the navigation of small boats.

Grosser, Morton. *Gossamer Odyssey: The Triumph of Human-Powered Flight.* Boston: Houghton Mifflin, 1981; 275 pp., illus.—Traces human-powered aviation from the early 1920's to the present; a remarkable engineering story.

Jablonski, Edward. *Man with Wings: A Pictorial History of Aviation.* New York: Doubleday, 1980; illus.—A very readable history for young people and adults.

Joels, Kerry M., and Gregory P. Kennedy. *The Space Operator's Manual.* New York: Ballantine, 1982; 160 pp., illus.—Instructions for operating and living in the space shuttle Columbia, with a fold-out instrument panel.

Joseph, James. *Chilton's Diesel Guide: Cars and Light Trucks.* Radnor, Pa.: Chilton, 1980; 218 pp., illus.—The advantages and drawbacks of diesel engines, and how they work, in terms comprehensible to the lay reader.

Kolin, Michael J., and Denise M. de la Rosa. *The Ten-Speed Bicycle.* Emmaus, Pa.: Rodale Press, 1979; 312 pp., illus.—Excellent discussion of the design concepts and components of the ten-speed, with repair and maintenance tips.

Knight, Geoffrey. *Concorde: The Inside Story.* New York: Stein & Day, 1976; 190 pp., illus.—The history of the development of the controversial supersonic aircraft.

Marshall, Jeff. *The Bicycle Rider's Bible.* New York: Doubleday, 1981; illus.—Covers every aspect of bicycle ownership and travel, in a readable style with many photographs.

Moolman, Valerie, ed. *The Road to Kitty Hawk.* New York: Time-Life Books, 1980; illus.—A superb book, exploring the age-old urge to fly, from the ancients to the Wrights.

Piggott, Stuart. *The Earliest Wheeled Transport.* Ithaca, N.Y.: Cornell University Press, 1983; 272 pp., illus.—A presentation of the evidence for the adoption and use of wheeled vehicles from earliest times to the Roman Empire.

Robinson, Anthony, ed. *In the Cockpit: Flying the World's Great Aircraft.* New York: Ziff-Davis, 1980; 304 pp., illus.—Fascinating anecdotal descriptions of more than 50 military aircraft, with short essays by the flyers.

Schultz, Neil. *The Complete Book of Safe Moped Operation and Repair.* New York: Dolphin/Doubleday, 1980; illus.—Describes the principles behind moped operation, with tips for purchase, maintenance, and repair.

Shacket, Sheldon R. *The Complete Book of Electric Vehicles.* Northbrook, Ill.: Domus/Quality Books, 1979; 168 pp., illus.—The history and recent resurgence of battery-driven vehicles.

Siberry, Mervyn. *Instruments of Flight: A Guide to the Pilot's Flight Panel of a Modern Airliner.* New York: Crane, Russak, 1974; 124 pp., illus.—Good description of the tools of modern aviation, kept at a nonmathematical level.

Taylor, John W. R., ed. *Jane's All the World's Aircraft.* New York: McGraw-Hill, revised yearly, illus.—Complete coverage of various aircraft, rockets, and spacecraft.

Von Braun, Wernher, and Frederick I. Ordway, III. *The Rocket's Red Glare.* Garden City, N.Y.: Anchor/Doubleday, 1976; 230 pp., illus.—How rockets developed from ancient to modern times, and the different kinds of rockets today.

Walsh, John Evangelist. *One Day at Kitty Hawk: The Untold Story of the Wright Brothers and the Airplane.* New York: Crowell, 1975; 305 pp., illus.—The story of the first successful powered flight is told in detail.

Whitt, Frank R., and David G. Wilson. *Bicycling Science.* Cambridge, Mass.: MIT Press, 1982; 364 pp., illus.—A technical guide to changing bicycle design.

COMMUNICATION

Eber, Dorothy H. *Genius at Work: Images of Alexander Graham Bell.* New York: Viking, 1982; 192 pp., illus.—The personality and pioneering experiments of the noted inventor.

Epstein, Sam, and Beryl Williams. *The First Book of Printing.* New York: Franklin Watts, 1974; illus.—Text suitable for grades 4–7.

Kao, Charles K. *Optical Fiber Systems.* New York: McGraw-Hill, 1982; 204 pp., illus.—The technology, design, and applications of fiber-optic technology.

Krishef, Robert K. *Playback: The Story of Recording Devices.* Minneapolis: Lerner, rev. ed., 1974—The technology of sound recording; for grades 5–11.

Leinwoll, Stanley. *From Spark to Satellite: A History of Radio Communication.* New York: Scribners, 1979; 242 pp., illus.—Interesting, thorough coverage of the development of radio.

Martin, James. *The Wired Society.* Englewood Cliffs, N.J.: Prentice-Hall, 1978; 250 pp.—Describes modern communication devices and how they affect society; very readable.

Meadow, Charles T. *Sounds and Signals: How We Communicate.* Philadelphia: Westminster Press, 1975; 95 pp., illus. —The methods and uses of communication in the world today and possible developments in the future.

O'Connor, Jerome J. *The Telephone: How It Works.* New York: Putnam, 1971, 94 pp., illus.—Clear presentation of the telephone's functions; many good diagrams; for grades 5–8.

The Radio Amateur's Handbook. Newington, Conn.: American Radio Relay League; revised annually—Standard manual for amateur radio enthusiasts; sometimes difficult.

Schicke, C. A. *Revolution in Sound.* Boston: Little, Brown, 1974; 246 pp., illus.—An account of the phonograph recording industry; for grade 7 and up.

Westcott, Charles G., and Richard F. Dubbe. *Tape Recorders —How They Work.* Indianapolis: Howard W. Sams, 2d ed., 1974; 240 pp., illus.—Complete and helpful book intended for the serious student technician or amateur hobbyist; for senior high school and up.

MATERIALS

Abisch, Roz, and Boche Kaplan. *Textiles.* New York: Franklin Watts, 1975; 64 pp.—Textiles, from the Stone Age to the present.

Hahn, James, and Lynn Hahn. *Plastics.* New York: Franklin Watts, 1974; 65 pp., illus.—History, chemistry, and uses of plastics; for senior high school students and other readers.

The International Book of Wood. New York: Simon & Schuster, 1977; 276 pp., illus.—The many uses of wood in art, architecture, and industry.

Lyttle, Richard B. *Paints, Inks and Dyes.* New York: Holiday House, 1974; 178 pp., illus.—Development and current technology in making pigments, dyes, and so forth; safe projects described; for grades 7–12.

OTHER

Electricity and Electronics

Buffington, Charles. *Your First Personal Computer.* New York: McGraw-Hill, 1983; 326 pp., illus.—Help in making an informed buying decision and ways to integrate it into everyday life.

Clifford, Martin. *Basic Electricity and Beginning Electronics.* Blue Ridge Summit, Pa.: TAB Books, 1973; 256 pp., illus.—A useful reference with good line drawings; for high school students.

Forester, Tom, ed. *The Microelectronics Revolution: The Complete Guide to the New Technology and Its Impact on Society.* Cambridge, Mass.: MIT Press, 1981; 589 pp.—Essays on the social implications of the new technology, detailed but within the lay person's grasp.

Goldberg, Kenneth P., and Robert D. Sherwood. *Microcomputers.* New York: John Wiley, 1983; 196 pp., illus.—A parent's guide to computers: components, software, informed buying; how they are being used in schools.

Kyle, James. *Electronics Unraveled: A New Common-Sense Approach.* Blue Ridge Summit, Pa.: TAB Books, 1974; 229 pp., illus., paper—An easy introduction to fundamentals of electronics and electricity, concluding with six projects; for junior high school and up.

Lachenbruch, David. *Videocassette Recorders: The Complete Home Guide.* New York: Everest House, 1979; 225 pp., illus.—Highly accurate, interesting, and sometimes humorous guide.

Microscopes and Their Use

Johnson, Gaylord, and Maurice Bleifield. *Hunting with the Microscope.* New York: Arco, rev. ed., 1976—Instructions on how to use the pocket lens and the compound microscope.

Klein, Aaron E. *The Electron Microscope: A Tool of Discovery.* New York: McGraw-Hill, 1974; 86 pp., illus.—The theory and development of this instrument.

Technology in the Home

Drake, George. *Everyone's Book of Hand and Small Power Tools.* Reston, Va.: Reston, 1974; 338 pp., illus.—Useful guide for the home carpenter.

Jackson, Albert, and David Day. *Tools and How to Use Them: An Illustrated Encyclopedia.* New York: Knopf, 1978; 352 pp., illus.—A most useful book for home carpenters, plumbers, gardeners, and others.

McClintock, Michael. *Homeowner's Energy Investment Handbook.* Andover, Mass.: Brick House, 1982; 116 pp., illus.—a guide to making money-saving, energy-efficient home improvements.

Mueller, Larry. *Successful Home Electrical Wiring.* Milwaukee, Wisc.: Structures Publishing, 1980; 144 pp., illus.—Thorough step-by-step manual for wiring or rewiring a house.

Miscellaneous

Asimov, Isaac. *A Choice of Catastrophes.* New York: Simon & Schuster, 1979; 384 pp.—Refreshingly optimistic view of how people can solve their problems using technology and intelligence creatively.

Baynes, Ken, and Francis Pugh. *The Art of the Engineer.* New York: Overlook Press, 1981; 240 pp., illus.—Engineering drawings demonstrating the skills of draftsmanship in a rapidly changing technological environment.

Cobb, Vicki. *Supersuits.* Philadelphia: Lippincott, 1975; 95 pp., illus.—Fascinating account of the special suits designed to protect against such environments as space, the deep ocean, and so on; for grades 5–9.

Danilov, Victor J. *Science and Technology Centers.* Cambridge, Mass.: MIT Press, 1982; 355 pp., illus.—Development and description of museums of science and technology.

Fuller, R. Buckminster. *Synergetics: Explorations in the Geometry of Thinking.* New York: Macmillan, 1982; 876 pp., illus.—Descriptions of Fuller's mathematical advances and practical inventions as well as his ways of looking at things.

Hammer, Mark J. *Water and Waste-water Technology.* New York: John Wiley, 1975; 512 pp., illus.—How municipalities obtain fresh water and dispose of wastewater.

Heavens, O. S. *Lasers.* New York: Scribners, 1973; 159 pp., illus.—Good introductory work, covering principles and kinds of lasers and their future uses; for the general reader.

Hopkins, Robert A. *The International (SI) Metric System and How It Works.* Tarzana, Calif.: AMJ Publishing/Polymetric Services, 1973; 281 pp., illus.—Contains several chapters of tables and conversion factors and includes many units used in industry.

Jones, Pamela. *Under the City Streets.* New York: Holt, Rinehart & Winston, 1979; 275 pp., illus.—All the technological mainstays of society found underground in a big city (New York), from water mains to subway trains.

Sagan, Carl. *Broca's Brain: Reflections on the Romance of Science.* New York: Random House, 1979; 347 pp.—Skillful and stylish essays on such diverse topics as astronomy, astrophysics, and robots.

Smith, Norman. *Man and Water: A History of Hydro-Technology.* New York: Scribners, 1976; 239 pp., illus.—How people have developed technologies for using water in agriculture and power generation.

NOBEL PRIZE WINNERS IN SCIENCE

Alfred Bernard Nobel, the 19th-century Swedish engineer who invented dynamite, left $9,000,000 in a fund to provide yearly awards for people whose work has benefited mankind. There are five Nobel Prizes—in physics, chemistry, medicine or physiology, literature, and for the promotion of peace. The physics and chemistry prizes are awarded by the Royal Academy of Science in Stockholm; the medicine prizes by the Karolinska Medical-Chirurgical Institute in Stockholm; the literature prizes by the Swedish Academy in Stockholm; the peace prizes by the Swedish Parliament. The names of candidates are submitted by persons qualified in the various fields. Although the winners are generally announced earlier in the year, the actual ceremony of awarding the prizes takes place annually on the anniversary of Nobel's death, December 10. A gold medal and a diploma accompany the money. The dollar value of the prize varies.

Following are the Nobel Prize winners in physics, chemistry, and medicine or physiology from the 1901, when the prizes were first awarded, to the present time. We give the specific contributions for which prizes were granted.

(AMERICAN-SWEDISH NEWS EXCHANGE)

Year	*Physics*	*Chemistry*	*Medicine or Physiology*
1901	*Wilhelm K. Roentgen* (Germany): discovery of Roentgen rays, or X rays.	*Jacobus H. van't Hoff* (Netherlands): discovery of laws of chemical dynamics and osmotic pressure.	*Emil A. von Behring* (Germany): research on use of serums against diphtheria.
1902	*Hendrik A. Lorentz* (Netherlands) and *Pieter Zeeman* (Netherlands): research on influence of magnetism upon radiation.	*Emil Fischer* (Germany): experiments in sugar and purin groups.	*Ronald Ross* (England): work on malaria.
1903	*Antoine-Henri Becquerel* (France): research on spontaneous radioactivity. *Pierre Curie* (France) and *Marie Curie* (France): series of outstanding discoveries in the field of radiation.	*Svante A. Arrhenius* (Sweden): theory of electrolytic dissociation.	*Niels R. Finsen* (Denmark): treatment of lupus vulgaris with light-rays.
1904	*John Strutt* (England): discovery of argon.	*Sir William Ramsay* (England): work on inert gases.	*Ivan P. Pavlov* (Russia): research on physiology of digestion.
1905	*Philipp Lenard* (Germany): work on cathode rays.	*Adolph von Baeyer* (Germany): research on organic dyes and aromatic hydrocarbons.	*Robert Koch* (Germany): work on tuberculosis.
1906	*Joseph J. Thomson* (England): research on passage of electricity through gases.	*Henry Moissan* (France): isolation of fluorine; development of electric furnace.	*Camillo Golgi* (Italy) and *Santiago Ramón y Cajal* (Spain): research on structure of nervous system.

Year	*Physics*	*Chemistry*	*Medicine or Physiology*
1907	*Albert A. Michelson* (U.S.): research on spectroscopy and metrology.	*Eduard Buchner* (Germany): discovery of cell-less fermentation; researches in the field of biochemistry.	*Charles L. A. Laveran* (France): research on role of protozoa in disease.
1908	*Gabriel Lippmann* (France): work on reproduction of colors by photography.	*Ernest Rutherford* (England): research on disintegration of elements and chemistry of radioactive substances.	*Paul Ehrlich* (Germany) and *Elie Matchnikoff* (Russia): work on immunity.
1909	*Guglielmo Marconi* (Italy) and *Karl Ferdinand Braun* (Germany): development of radio.	*Wilhelm Ostwald* (Germany): research on catalysis, chemical equilibrium, and rate of chemical reaction.	*Emil Theodor Kocher* (Switzerland): work on thyroid gland.
1910	*Johannes D. van der Waals* (Netherlands): theory of equation of state for gases and liquids.	*Otto Wallach* (Germany): work on alicyclic compounds.	*Albrecht Kossel* (Germany): research on chemistry of the cell.
1911	*Wilhelm Wien* (Germany): laws of radiation of heat.	*Marie Curie* (France): discovery of radium and polonium.	*Allvar Gullstrand* (Sweden): work on dioptrics.
1912	*Gustaf Dalén* (Sweden): invention of automatic regulators for lighting lighthouses and light buoys.	*Victor Grignard* (France): development of Grignard reagent. *Paul Sabatier* (France): work on hydrogenation of organic compounds.	*Alexis Carrel* (U. S.): work on ligature and grafting of blood vessels and organs.
1913	*H. Kamerlingh-Onnes* (Netherlands): research paving way for production of liquid helium.	*Alfred Werner* (Switzerland): work on linking up atoms within the molecule.	*Charles Richet* (France): research on anaphylaxy.
1914	*Max von Laue* (Germany): discovery of the diffraction of X rays as they pass through crystals.	*Theodore W. Richards* (U. S.): determining atomic weight of many elements.	*Robert Bárány* (Austria): research on the physiology and pathology of vestibular system within the body.
1915	*W. H. Bragg* (England) and *W. L. Bragg* (England): analysis of crystal structure by use of X rays.	*Richard Willstaetter* (Germany): work on nature of chlorophyll and other coloring matter of plants.	No award.
1916	No award.	No award.	No award.
1917	*Charles G. Barkla* (England): discovery of Roentgen radiation of the elements.	No award.	No award.
1918	*Max Planck* (Germany): work on quantum theory.	*Fritz Haber* (Germany): synthetic production of ammonia by the Haber process.	No award.
1919	*Johannes Stark* (Germany): decomposition of spectrum lines by electric fields; discovery of Doppler effect in canal rays.	No award.	*Jules Bordet* (Belgium): research on immunity.
1920	*Charles E. Guillaume* (Switzerland): research on nickel-steel alloys.	*Walther Nernst* (Germany): work on thermochemistry.	*Schack August Krogh* (Denmark): research on motor mechanism of capillaries.

Year	*Physics*	*Chemistry*	*Medicine or Physiology*
1921	*Albert Einstein* (Germany): basis of photoelectric effect.	*Frederick Soddy* (England): work on isotopes.	No award.
1922	*Niels Bohr* (Denmark): research on structure of atoms and radiations from atoms.	*Francis W. Aston* (England): discovery of isotopes in nonradioactive elements.	*Archibald V. Hill* (England): work on heat production in muscles. *Otto Meyerhof* (Germany): discovery of correlation between consumption of oxygen and production of lactic acid in the muscles.
1923	*Robert A. Millikan* (U. S.): research on photoelectric phenomena and charge on electron.	*Fritz Pregl* (Austria): microanalysis of organic substances.	*Frederick G. Banting* (Canada) and *John J. R. McLeod* (Canada): discovery of insulin.
1924	*Karl M. G. Siegbahn* (Sweden): work on X-ray spectroscope.	No award.	*Willem Einthoven* (Netherlands): discovery of mechanism of electrocardiogram.
1925	*James Franck* (Germany) and *Gustav Hertz* (Germany): discovery of laws governing impact of electrons upon atoms.	*Richard Zsigmondy* (Germany; born in Austria): work on colloid solutions.	No award.
1926	*Jean-Baptiste Perrin* (France): work on discontinuous structure of matter; equilibrium of sedimentation.	*Theodor Svedberg* (Sweden): work on dispersion systems.	*Johannes Fibiger* (Denmark): researches on cancer.
1927	*Arthur H. Compton* (U. S.): discovery of Compton phenomenon. *Charles T. R. Wilson* (England): paths taken by electrically charged particles.	*Heinrich Wieland* (Germany): work on bile acids and similar substances.	*Julius Wagner-Jauregg* (Austria): use of malaria inoculation in treating dementia paralytica.
1928	*Owen W. Richardson* (England): work on thermionics: Richardson Law.	*Adolph Windaus* (Germany): work on constitution of sterols, their connection with vitamins.	*Charles Nicolle* (France): work on typhus exanthematicus.
1929	*Prince Louis-Victor de Broglie* (France): discovery of wave character of electrons.	*Arthur Harden* (England) and *Hans K. A. S. von Euler-Chelpin* (Sweden): work on fermentation of sugars.	*Sir Frederick G. Hopkins* (England): discovery of growth-promoting vitamins. *Christiaan Eijkman* (Netherlands): discovery of antineuritic vitamins.
1930	*Sir Chandrasekhara V. Raman* (India): work on diffusion of light; discovery of Raman effect.	*Hans Fischer* (Germany): work on coloring matter of blood and leaves; synthesis of hemin.	*Karl Landsteiner* (U. S.): discovery of human blood groups.
1931	No award.	*Friedrich Bergius* (Germany) and *Karl Bosch* (Germany): development of chemical high-pressure methods.	*Otto Warburg* (Germany): work on respiratory ferment.
1932	*Werner Heisenberg* (Germany): development of quantum mechanics.	*Irving Langmuir* (U. S.): work on surface chemistry.	*Sir Charles S. Sherrington* (England) and *Edgar D. Adrian* (England): functions of neuron.

Year	*Physics*	*Chemistry*	*Medicine or Physiology*
1933	*Paul A. M. Dirac* (England) and *Erwin Schroedinger* (Austria): discovery of various new forms of the atomic theory.	No award.	*Thomas H. Morgan* (U. S.): research on hereditary function of chromosomes.
1934	No award.	*Harold C. Urey* (U. S.): discovery of heavy hydrogen.	*George R. Minot* (U. S.), *William P. Murphy* (U. S.), and *George H. Whipple* (U. S.): discovery of liver therapy in treatment of anemia.
1935	*James Chadwick* (England): discovery of neutron.	*Frédéric and Iréne Joliot-Curie* (France): synthesis of new radioactive elements.	*Hans Spemann* (Germany): discovery of organizer effect in embryonic development.
1936	*Victor F. Hess* (Austria): discovery of cosmic radiation. *Carl D. Anderson* (U. S.): discovery of positron.	*Peter J. W. Debye* (Germany): work on dipole moments and diffraction of X rays and electrons in gases.	*Sir Henry H. Dale* (England) and *Otto Loewi* (Austria): work on chemical transmission of nerve impulses.
1937	*Clinton J. Davisson* (U. S.) and *George P. Thomson* (England): discovery of diffraction of electrons by crystals.	*Walter N. Haworth* (England): research on carbohydrates and vitamin C. *Paul Karrer* (Switzerland): work on carotenoids, flavins, and vitamins A and B.	*Albert Szent-Györgyi von Nagyrapolt* (Hungary): research on biological combustion.
1938	*Enrico Fermi* (Italy): identification of new radioactive elements; nuclear reactions effected by slow neutrons.	*Richard Kuhn* (Germany): study of carotenoids; research on vitamins.	*Corneille Heymans* (Belgium): research on importance of sinus and aorta mechanisms in regulation of respiration.
1939	*Ernest O. Lawrence* (U. S.): development of cyclotron.	*Adolph F. Butenandt* (Germany): work on sexual hormones. *Leopold Ruzicka* (Switzerland): research on the polymethylenes.	*Gerhard Domagk* (Germany): discovery of antibacterial effect of prontocilate.
1940	No award.	No award.	No award.
1941	No award.	No award.	No award.
1942	No award.	No award.	No award.
1943	*Otto Stern* (U. S.): detection of magnetic moments of protons.	*Georg von Hevesy* (Hungary): work on use of isotopes as chemical indicators.	*Edward A. Doisy* (U. S.) and *Henrik Dam* (Denmark): discovery of the chemical nature of vitamin K.
1944	*Isidor Isaac Rabi* (U. S.): work on magnetic properties of atomic particles.	*Otto Hahn* (Germany): work on atomic fission.	*Joseph Erlanger* (U. S.) and *Herbert S. Gasser* (U. S.): research on functions of nerve threads.
1945	*Wolfgang Pauli* (Austria): work on atomic fission.	*Artturi Virtanen* (Finland): research in field of fodder conservation.	*Sir Alexander Fleming* (England), *Ernst Boris Chain* (Germany), and *Sir Howard Walter Florey* (England): development of penicillin, derived from the mold *Penicillium notatum*.
1946	*Percy W. Bridgman* (U. S.): work on high-pressure physics.	*James B. Sumner* (U. S.): crystallizing of enzymes. *John H. Northrop* (U. S.) and *Wendell M. Stanley* (U. S.): preparation of enzymes and virus proteins.	*Herman J. Muller* (U. S.): research on hereditary effects of X rays on genes.

Year	*Physics*	*Chemistry*	*Medicine or Physiology*
1947	*Sir Edward Appleton* (England): discovery of layer reflecting radio short waves in ionosphere.	*Sir Robert Robinson* (England): work on plant substances.	*Carl F. Cori* (U. S.) and *Gerty T. Cori* (U. S.): work on animal-starch metabolism. *Bernardo Houssay* (Argentina): hormone study of pituitary gland.
1948	*Patrick M. S. Blackett* (England): improvement on Wilson cloud chambers; series of outstanding discoveries in cosmic radiation.	*Arne Tiselius* (Sweden): biochemical discoveries; isolation of mouse-paralysis virus.	*Paul Mueller* (Switzerland): discovery of insecticidal properties of DDT.
1949	*Hideki Yukawa* (Japan): mathematical prediction of existence of meson.	*William F. Giauque* (U. S.; born in Canada): research in field of thermodynamics.	*Walter R. Hess* (Switzerland): discovery of how parts of brain control different parts of body. *Antonio Caetano de Abreu Freire Egas Moniz* (Portugal): development of neurosurgery for treatment of mental illness.
1950	*Cecil Frank Powell* (England): development of simple photographic method for studying atomic nucleus; work on mesons.	*Otto Diels* (Germany) and *Kurt Alder* (Germany): development of diene synthesis, a method by which certain aromatic compounds are made artificially.	*Philip S. Hench* (U. S.), *Edward C. Kendall* (U. S.), and *Tadeus Reichstein* (Switzerland): discoveries regarding hormones of adrenal cortex, their structure, and their biological effect.
1951	*Sir John Cockcroft* (England) and *E. T. S. Walton* (Ireland): experiments in splitting atomic nuclei with artificially propelled "bullets."	*Glenn T. Seaborg* (U. S.) and *Edward M. McMillan* (U. S.): discovery of plutonium.	*Max Theiler* (South Africa): discovery of effective vaccines protecting human beings against yellow fever.
1952	*Felix Bloch* (U. S.) and *Edward M. Purcell* (U. S.): development of new method of measuring magnetic fields in atomic nuclei.	*Archer Martin* (England) and *Richard Synge* (Scotland): development of paper partition chromatography.	*Selman A. Waksman* (U. S.): discovery of streptomycin, first effective antibiotic against tuberculosis.
1953	*Fritz Zernike* (Netherlands): development of microscope for study of living cells colored by light waves.	*Hermann Staudinger* (Germany): work on synthesizing of fiber.	*Fritz A. Lipmann* (U. S.) and *Hans A. Krebs* (England): research on basic life processes carried on in human cells.
1954	*Max Born* (Germany): fundamental work in quantum mechanics. *Walther Bothe* (Germany): development of coincidence method in the study of cosmic radiation.	*Linus Pauling* (U. S.): work on the nature of chemical bonds, especially as applied to the structure of complicated substances.	*John F. Enders* (U. S.), *Thomas H. Weller* (U. S.), and *Frederick C. Robbins* (U. S.): discovery that the poliomyelitis virus is capable of growing in cultures of different tissues.
1955	*Willis E. Lamb* (U. S.): work on the hydrogen spectrum. *Polykarp Kusch* (U. S.): precision measurement of the magnetic moment of the electron.	*Vincent du Vigneaud* (U. S.): identification and synthesis of two hormones—oxytocin and vasopressin.	*Hugo Theorell* (Sweden): work on the nature and action of oxidation enzymes.
1956	*William B. Shockley* (U. S.), *Walter H. Brattain* (U. S.), and *John Bardeen* (U. S.): de-	*Sir Cyril N. Hinshelwood* (England) and *Nikolai N. Semenov* (U.S.S.R.): independent	*Dickinson W. Richards, Jr.* (U. S.), *Andre Cournand* (U. S.), and *Werner Forssman* (F. G. R.): de-

Year	*Physics*	*Chemistry*	*Medicine or Physiology*
	velopment of the electronic transistor.	but parallel research on chemical kinetics leading to the improvement of the internal combustion engine and the development of modern plastics.	velopment of a new technique of diagnosis and treatment of heart disease.
1957	*Tsung Dao Lee* (U. S.) and *Chen Ning Yang* (U. S.): atomic research disproving the principle of conservation of parity.	*Sir Alexander Todd* (England): research on nucleotides and nucleotide enzymes, chemical compounds known to be factors in heredity.	*Daniel Bovet* (Italy): development of antihistamines and drugs based on curare—a South American Indian arrowtip poison—to desensitize and relax muscles subjected to prolonged surgery.
1958	*PavelA.Cherenkov*(U.S.S.R.). *Ilya M. Frank* (U.S.S.R.). and *Igor E. Tamm* (U.S.S.R.): work with high-speed subatomic particles.	*Frederick Sanger* (England): research on the structure of insulin.	*Joshua Lederberg* (U. S.), *Edward L. Tatum* (U. S.), and *George W. Beadle* (U. S.): research in genetics.
1959	*Emilio Segre* (U. S.) and *Owen Chamberlain* (U. S.): proof of existence of anti-proton, negative counterpart of proton.	*Jaroslav Heyrovsky* (Czechoslovakia): development of electrolytic method of chemical analysis.	*Arthur Kornberg* (U. S.) and *Severo Ochoa* (U. S.): work on RNA and DNA.
1960	*Donald A. Glaser* (U. S.): development of bubble chamber, used in measuring energy of atoms accelerated in atom smashers.	*Willard F. Libby* (U. S.): development of radiocarbon dating technique.	*Peter B. Medawar* (England) and *Macfarlane Burnet* (Australia): breaking of "immunity barrier" that (with few exceptions) had prevented permanent transplants of different body parts.
1961	*Robert Hofstadter* (U. S.) and *Rudolf Moessbauer* (F.G.R.): Hofstadter for work on core of atom; Moessbauer for gamma-ray research.	*Melvin Calvin* (U. S.): research on carbon-dioxide assimilation in plants.	*Georg von Bekesy* (U. S.): work on mechanics of hearing.
1962	*Lev Davidovich Landau* (U.S.S.R.): researches in field of cryogenics.	*John C. Kendrew* (England) and *Max F. Perutz* (England): use of X rays to determine position of atoms in two protein molecules—myoglobin and hemoglobin.	*Francis H. C. Crick* (England), *James D. Watson* (U. S.), and *Maurice H. F. Wilkins* (England): determination of structure of DNA.
1963	*Eugene P. Wigner* (U. S.), *Maria G. Mayer* (U. S.), and *J. Hans D. Jensen* (F. G. R.): work on the structure of the atomic nucleus.	*Carl Ziegler* (F. G. R.) and *Giulio Natta* (Italy): polymerization of hydrocarbon molecules into complex compounds of industrial value.	*Alan L Hodgkin* (England), *Andrew F. Huxley* (England), and *John C. Eccles* (Australia): work on the nature and transmission of nerve impulses.
1964	*Charles H. Townes* (U. S.), *Aleksander M. Prokhorov* (U.S.S.R.), and *Nikolai G. Basov* (U.S.S.R.): discovery and development of masers and lasers.	*Dorothy Crowfoot Hodgkin* (England): determination of structures of vital biochemical compounds, including vitamin B_{12}, through use of X rays.	*Feodor Lynen* (F. G. R.) and *Konrad E. Bloch* (U. S.): researches on cholesterol.
1965	*Julian Schwinger* (U. S.), *Richard P. Feynman* (U. S.), and *Shinichiro Tomonaga*	*Robert B. Woodward* (U. S.): work on syntheses of complicated organic compounds.	*André Lwoff* (France), *Jacques Monod* (France), and *François Jacob* (France): work on the

Year	*Physics*	*Chemistry*	*Medicine or Physiology*
	(Japan): researches on mathematical relationships between elementary particles.		chemical basis of genes.
1966	*Alfred Kastler* (France): basic research that led to the development of the laser.	*Robert S. Mulliken* (U. S.): fundamental work on chemical bonds and electronic structure.	*Charles B Huggins* (U. S.) and *Francis P. Rous* (U. S.): outstanding cancer research.
1967	*Hans A. Bethe* (U. S.): work on nuclear reactions, especially discoveries concerning the energy of stars.	*Manfred Eigen* (F. G. R.), *Ronald G. W. Norrish* (England), and *George Porter* (England): studies of extremely fast chemical reactions.	*Haldan K. Hartline* (U. S.), *George Wald* (U. S.), and *Ragnar Granit* (Sweden): discoveries concerning chemical and physical visual processes.
1968	*Luis W. Alvarez* (U. S.): detection of new atomic particles with hydrogen bubble chamber.	*Lar Onsager* (U. S.): work on irreversible chemical processes.	*Marshall W. Nirenberg* (U. S.), *Robert W. Holley* (U. S.), and *Har Gobind Khorana* (U. S.): research on nucleic acids.
1969	*Murray Gell-Man* (U. S.): research and theories on atomic particles.	*Derek H. R. Barton* (England) and *Odd Hassel* (Norway): conformational analysis of the structure of organic compounds.	*Max Delbrück* (U. S.) and *Salvador Luria* (U. S.): research on molecular genetics of viruses.
1970	*Louis E. F. Néel* (France) and *Hannes O. G. Alfvén* (Sweden): Néel for work on magnetism; Alfvén for research on plasmas, or ionized gases.	*Luis F. Leloir* (Argentina): work on biochemistry of sugar and higher carbohydrates.	*Bernard Katz* (England), *Ulf von Euler* (Sweden), and *Julius Axelrod* (U. S.): work on chemistry of nerve impulses.
1971	*Dennis Gabor* (U. S.): development of holography, or three-dimensional lensless photography.	*Gerhard Herzberg* (Canada): work on molecular structure and free radicals.	*Earl W. Sutherland, Jr.* (U. S.): work on cyclic AMP, a regulator of hormone activity in the body.
1972	*John Bardeen* (U. S.), *Leon N. Cooper* (U. S.), and *John R. Schrieffer* (U. S.): work on theory of electrical superconductivity in metals at very low temperatures.	*Christian B. Anfinsen* (U. S.), *Stanford Moore* (U. S.), and *William H. Stein* (U. S.): work on enzyme ribonuclease, its formation and effects in living cells.	*Gerald M. Edelman* (U. S.) and *Rodney R. Porter* (England): research on chemical structure of antibodies, part of immunity system.
1973	*Leo Esaki* (Japan), *Ivar Giaever* (U. S.), and *Brian D. Josephson* (England): research on electronic tunneling in solids.	*Ernst O. Fischer* (F. G. R.) and *Geoffrey Wilkinson* (England): work on auto exhaust pollutants.	*Konrad Z. Lorenz* (Austria), *Karl von Frisch* (Austria), and *Nikolaas Tinbergen* (Netherlands): research on animal behavior (ethology).
1974	*Martin Ryle* (England) and *Antony Hewish* (England): research in radio astronomy.	*Paul J. Flory* (U. S.): research on the structure of plastics and other polymers.	*Albert Claude* (U. S.), *George Emil Palade* (U. S.), and *Christian Rene de Duve* (Belgium): research in cell biology.
1975	*Aage Bohr* (Denmark), *Ben R. Mottelson* (Denmark), and *James Rainwater* (U. S.): development of the theory of the structure of the atomic nucleus; research in nuclear structure.	*John W. Cornforth* (Australia) and *Vladimir Prelog* (Switzerland): synthesis of important organic compounds; research in stereochemistry.	*Renato Dulbecco* (Italy), *Howard M. Temin* (U. S.), and *David Baltimore* (U. S.): research on the role that viruses play in the growth of tumors.

Year	*Physics*	*Chemistry*	*Medicine or Physiology*
1976	*Burton Richter* (U.S.) and *Samuel C. C. Ting* (U.S.): discovery of the "J" particle, a new kind of subatomic particle.	*William N. Lipscomb* (U.S.): analysis of the structure of boranes, a group of unusual inorganic compounds.	*Baruch S. Blumberg* (U.S.) and *D. Carleton Gajdusek* (U.S.): Blumberg for discovery of hepatitis antigens; Gajdusek for how the disease kuru is transmitted.
1977	*John H. Van Vleck* (U.S.), *Philip W. Anderson* (U.S.), and *Sir Nevill F. Mott* (England): independent contributions to solid-state physics.	*Ilya Prigogine* (Belgium): work on thermodynamics.	*Rosalyn S. Yalow* (U.S.), *Roger C. L. Guillemin* (U.S.), and *Andrew V. Schally* (U.S.): independent research on human hormones.
1978	*Arno A. Penzias* (U.S.) and *Robert W. Wilson* (U.S.): for detecting background radiation, which supports the "big bang" theory of creation of the universe. *Pyotr Leonidovich Kapitsa* (U.S.S.R.): for pioneering work in low-temperature physics.	*Peter Mitchell* (England): for a new theory of how energy is transferred in cells.	*Daniel Nathans* (U.S.), *Hamilton O. Smith* (U.S.), and *Werner Arber* (Switzerland): for work with restriction enzymes, of which Dr. Arber was the discoverer.
1979	*Sheldon L. Glashow* (U.S.), *Abdus Salam* (Pakistan), and *Steven Weinberg* (U.S.): for calculations contributing to a theory that unifies two basic forces—electromagnetism, and the "weak interaction," which causes radioactivity in certain atoms.	*Herbert C. Brown* (U.S.) and *Georg Wittig* (West Germany): for devising a method of synthesizing biologically active substances such as hydrocortisone.	*Allan MacLeod Cormack* (U.S.) and *Godfrey Newbold Hounsfield* (England): for developing the computer axial tomographic scanner, which is a computer-assisted X-ray apparatus.
1980	*James W. Cronin* (U.S.) and *Val L. Fitch* (U.S.): for discoveries concerning the symmetry of subatomic particles.	*Paul Berg* (U.S.), *Walter Gilbert* (U.S.), and *Fredrick Sanger* (England): for development of methods for mapping and manipulating DNA.	*Baruj Benacerraf* (U.S.), *George D. Snell* (U.S.), and *Jean Dausset* (France): for discoveries concerning the genetics of the immune system.
1981	*Nicolaas Bloembergen* (U.S.) and *Arthur Schawlow* (U.S.): for using lasers to analyze the chemical makeup of substances. *Kai Siegbahn* (Sweden): for a focusing technique using X rays and ultraviolet light in chemical analysis.	*Kenichi Fukui* (Japan) and *Roald Hoffmann* (U.S.): for using quantum mechanics to explain chemical reactions.	*Roger W. Sperry* (U.S.): for demonstrating specialization of the hemispheres of the brain. *David H. Hubel* (U.S.) and *Torsten N. Wiesel* (U.S.): for studies of how the brain processes visual information.
1982	*Kenneth G. Wilson* (U.S.): for explaining phenomena inherent in such phase changes as that from solid to liquid and from magnetic to nonmagnetic.	*Aaron Klug* (England): for development of techniques for studying the intricate structures of viruses and other biologically important structures.	*Sune Bergstrom* (Sweden), *Bengt I. Samuelsson* (Sweden), and *John R. Vane* (England): for work on the hormonelike substances known as prostaglandins.
1983	*William A. Fowler* (U.S.) and *Subrahmanyan Chandrasekhar* (U.S.): for explorations of what happens as stars age, exhaust their nuclear fuel, build heavy elements, and collapse.	*Henry Taube* (U.S.): for work in the mechanism of the transfer of electrons in metals in chemical reactions.	*Barbara McClintock* (U.S.): for the discovery that the genes of a plant can transpose from one chromosome to another.

MATHEMATICAL SYMBOLS

Σ	sigma; sum of the quantities in a statement preceded by that sign
Δx	an increment, or change in *x*
$\int$	integral sign
$n!$	*n* factorial; product of all integers up to and including *n*
$'$	prime
$''$	double prime
$\measuredangle$	angle
$\perp$	perpendicular
$//$	parallel
π	pi; ratio of the circumference of a circle to its diameter—approximately 3.14
o	origin of a coordinate system
sin	sine of an angle
cos	cosine of an angle
tan	tangent of an angle
cot	cotangent of an angle
sec	secant of an angle
csc	cosecant of an angle
$A = B$	set A coincides with set B
$A \subset B$	set A is a subset of B
$A \cup B$	union of sets A and B
$A \cap B$	intersection of sets A and B
$\varnothing$	the null set

$+$	positive; plus
$-$	negative; minus
$\times$	multiplied by
$\overline{)}$ or $\div$	divided by
$=$	equals; is equal to
$\neq$	does not equal; is not equal to
$\cong$	congruent; approximately equal to
$\sim$	equivalent
$>$	is greater than
$\geq$	is greater than or equal to
$<$	is less than
$\leq$	is less than or equal to
α	is directly proportional to
∞	infinity
$\lvert x \rvert$	absolute value of *x*
a^n	*a*, a number, raised to the *n*th power
$\sqrt{a}$	square root of *a*
$\sqrt[n]{a}$	*n*th root of *a*
i	square root of -1
e	Euler's number; base in system of natural logarithms—approximately 2.718
$\mathbf{log}_a x$	logarithm of *x* in base *a*
$\mathbf{ln}\, x$	logarithm of *x* in base *e*: natural logarithm of *x*
antilog	antilogarithm

IMPORTANT CONSTANTS FOR THE PHYSICAL SCIENCES

Velocity of light in a vacuum	c	299,792,458 meters/second
Velocity of sound in air (at STP)		330 meters/second
Acceleration of gravity at the earth's surface	g	9.8 meters/second^2
Gravitational constant	G	6.67 Newton-meters/second^2
Planck's constant	h	6.63×10^{-34} joule-second
Avogadro's number	N	6.02×10^{23} molecules/mole
Gas constant	R	8,300 joules/kilomole-°K
Faraday constant	F	96,500,000 coulombs/kilomole
Atomic mass unit	amu	1.66×10^{-27} kilogram
Rest mass of the electron	M_e	9.1×10^{-31} kilogram
Rest mass of the proton	M_p	1.67×10^{-27} kilogram
Rest mass of the neutron	M_n	1.67×10^{-27} kilogram
Atmosphere	atm	1 Newton/centimeter^2
Density of water at 4° Celsius		1 gram/centimeter^3
Density of dry air at STP		0.0013 gram/centimeter^3

Specific heat of water	1 kilocalorie/kilogram-°Celsius
Specific heat of water vapor	0.5 kilocalorie/kilogram-°Celsius
Specific heat of ice	0.5 kilocalorie/kilogram-°Celsius
Specific heat of dry air	kilocalorie/kilogram-°Celsius
Boiling point of water	100° Celsius
Freezing point of water	0° Celsius
Heat of fusion of ice	80 kilocalories/kilogram
Heat of vaporization of water	540 kilocalories/kilogram
Light-year	9,600,000,000,000 kilometers
Parsec	3.26 light-years
Astronomical unit (average distance from earth to sun)	149,600,000 kilometers
Distance from the earth to the moon (average)	384,400 kilometers
Mass of the sun	1.97×10^{33} grams
Mass of the earth	5.98×10^{27} grams
Mass of the moon	7.38×10^{24} grams
Diameter of the sun (equator)	1,392,000 kilometers
Diameter of the earth (equator)	12,750 kilometers
Diameter of the moon (equator)	3,480 kilometers
Mean density of the sun	1.4 grams/centimeter^{3}
Mean density of the earth	5.5 grams/centimeter^{3}
Mean density of the moon	3.3 grams/centimeter^{3}

UNITS AND SYMBOLS

Unit	Symbol	Unit	Symbol	Unit	Symbol
acre	acre	dram, avoirdupois	dr avdp	milliliter	ml
barrel	bbl	fathom	fath	millimeter	mm
bushel	bu	foot	ft	ounce	oz
carat	c	gallon	gal	ounce, avoirdupois	oz avdp
Celsius, degree	°C	gram	g	ounce, liquid	liq oz
centigram	cg	hectare	ha	ounce, troy	oz tr
centiliter	cl	hectogram	hg	pint, liquid	liq pt
centimeter	cm	hectoliter	hl	pound	lb
cubic centimeter	cm^{3}	hectometer	hm	pound, avoirdupois	lb avdp
cubic decimeter	dm^{3}	inch	in	pound, troy	lb tr
cubic dekameter	dam^{3}	International Nautical Mile	INM	quart, liquid	liq qt
cubic foot	ft^{3}	Kelvin, degree	°K	second	s
cubic hectometer	hm^{3}	kilogram	kg	square centimeter	cm^{2}
cubic inch	in^{3}	kiloliter	kl	square decimeter	dm^{2}
cubic kilometer	km^{3}			square dekameter	dam^{2}
cubic meter	m^{3}	kilometer	km	square foot	ft^{2}
cubic mile	mi^{3}	liquid	liq	square hectometer	hm^{2}
cubic millimeter	mm^{3}	liter	liter	square inch	in^{2}
cubic yard	yd^{3}	meter	m	square kilometer	km^{2}
decigram	dg	microgram	μg	square meter	m^{2}

deciliter	dl	microinch	μin	square mile	mi^2
decimeter	dm	microliter	μl	square millimeter	mm^2
dekagram	dag	micron	μm	square yard	yd^2
dekaliter	dal	mile	mi	ton, long	long ton
dekameter	dam	milligram	mg	ton, metric	t
				ton, short	short ton
				yard	yd

COMPARISON OF TEMPERATURE SCALES

Two temperature scales are in common use today: the *Celsius* (sometimes called the *centigrade*) *scale* and the *Fahrenheit scale*. In scientific work, the *Kelvin scale* is generally used. Another scale, the *Réaumur scale*, is used in some countries. In the Celsius scale, the freezing point of water is 0°, and the boiling point of water is 100°. In the Kelvin scale, the degrees of rise in temperature have the same intervals as in the Celsius scale, but 0° Kelvin is absolute zero, the temperature at which atomic and molecular motion would theoretically cease. In the Celsius scale, absolute zero would be −273.16°. In the Fahrenheit scale, the freezing point of water is 32° and the boiling point is 212°, while absolute zero would be −459.69°.

There are simple conversion formulas for changing between these different temperature scales, as follows:

(°Celsius × 9/5) + 32 = °Fahrenheit
(°Fahrenheit − 32) × 5/9 = °Celsius
1 °Celsius = 1.8 °Fahrenheit
°Kelvin = °Celsius + 273.16
°Celsius = °Kelvin − 273.16

([°Kelvin − 273.16] × 9/5) + 32 = °Fahrenheit
([°Fahrenheit − 32] × 5/9) + 273.16 = °Kelvin
°Réaumur × 5/4 = °Celsius
°Réaumur × 9/4 + 32 = °Fahrenheit

Listed below are a few conversions between Celsius and Fahrenheit

°Fahrenheit	*°Celsius*	*°Fahrenheit*	*°Celsius*
−40	−40	77	25
−31	−35	86	30
−22	−30	104	40
−13	−25	122	50
0	−17.8	131	55
5	−15	140	60
14	−10	158	70
23	− 5	167	75
32	0	185	85
50	10	194	90
68	20	212	100

THE METRIC SYSTEM

The metric system, established in France in 1793, is based on the meter. Adopted in many countries, the system is in general use for scientific measurements. Originally, 1/10,000,000 of the earth's quadrant passing through Paris was taken as the length of the meter. Later it was defined as the distance between two lines on a platinum-iridium bar kept at the International Bureau of Weights and Measures in Sèvres, France. In 1960 the meter was redefined as 1,650,763.73 times the wavelength of krypton 86 light, giving an accuracy of one part in 250,000,000. In 1983 the meter was defined again, as the distance light travels through space in 1/299,792,458 of a second. Accuracy can be measured to one part in 10,000,000,000,000.

Linear Measure

10 millimeters = 1 centimeter
10 centimeters = 1 decimeter
10 decimeters = 1 meter
10 meters = 1 dekameter
10 dekameters = 1 hectometer
10 hectometers = 1 kilometer

Square Measure (Area)

100 square millimeters = 1 square centimeter
100 square centimeters = 1 square decimeter
100 square decimeters = 1 square meter
100 square meters = 1 square dekameter
100 square dekameters = 1 square hectometer
100 square hectometers = 1 square kilometer
10,000 square meters = 1 hectare

Cubic Measure (Volume)

1,000 cubic millimeters = 1 cubic centimeter
1,000 cubic centimeters = 1 cubic decimeter
1,000 cubic decimeters = 1 cubic meter

Measure of Capacity

10 milliliters = 1 centiliter
10 centiliters = 1 deciliter
10 deciliters = 1 liter
10 liters = 1 dekaliter
10 dekaliters = 1 hectoliter
10 hectoliters = 1 kiloliter

Weights

10 milligrams = 1 centigram
10 centigrams = 1 decigram
10 decigrams = 1 gram
10 grams = 1 dekagram
10 dekagrams = 1 hectogram
10 hectograms = 1 kilogram
1,000 kilograms = 1 metric ton

U.S. WEIGHTS AND MEASURES

The United States used English standards of weight and measure until 1893. In that year the government decided to base the standard yard and pound on metric standards. For example, the American inch was defined as 2.54005 centimeters. American standards thus became independent of British ones, since the British inch and pound used in commerce are slightly different. In scientific work, however, the standards of both countries are the same.

Linear Measure

12 inches = 1 foot
3 feet = 1 yard
5½ yards = 1 rod
40 rods = 1 furlong
8 furlongs = 1 mile
5,280 feet = 1 mile
3 miles = 1 league

Cubic Measure (Volume)

1,728 cubic inches = 1 cubic foot
27 cubic feet = 1 cubic yard
(measure for cordwood)
16 cubic feet = 1 cord foot (4′ × 4′ × 1′)
8 cord feet or 128 cubic feet = 1 cord (4′ × 4′ × 8′)

Square Measure (Area)

144 square inches = 1 square foot
9 square feet = 1 square yard
30¼ square yards = 1 square rod
160 square rods = 1 acre
43,560 square feet = 1 acre
640 acres = 1 square mile

Nautical Measure

6 feet = 1 fathom
1 cable's length = 100 fathoms, ordinary; 720 feet
1 nautical mile = 6,080.20 feet
1 knot = unit of speed, equal to 1 nautical mile per hour

Dry Measure

2 pints = 1 quart = 67.20 cubic inches
8 quarts = 1 peck = 537.61 cubic inches
4 pecks = 1 bushel = 2,150.42 cubic inches

Liquid Measure

4 gills = 1 pint = 28.885 cubic inches
2 pints = 1 quart = 57.75 cubic inches
4 quarts = 1 gallon = 231.0 cubic inches

Avoirdupois Weight

16 drams = 1 ounce
16 ounces = 1 pound
100 pounds = 1 quintal
2,000 pounds = 1 short ton
2,240 pounds = 1 long ton

Troy Weight

3.086 grains = 1 carat
24 grains = 1 pennyweight
20 pennyweights = 1 ounce
12 ounces = 1 pound

Time Measure

60 seconds = 1 minute
60 minutes = 1 hour
24 hours = 1 day
7 days = 1 week
365 days or 12 months = 1 year
366 days = 1 leap year
100 years = 1 century

Apothecaries' Weight

20 grains = 1 scruple
3 scruples = 1 dram
8 drams = 1 ounce
12 ounces = 1 pound

Circular Measure

60 seconds = 1 minute
60 minutes = 1 degree
60 degrees = 1 sextant
90 degrees = 1 quadrant
360 degrees = 1 circumference

COMMON CONVERSION FACTORS

Linear Measure

US to Metric	Metric to US
1 in = 25.4 mm (exactly)	1 mm = 0.0393701 in
1 in = 2.54 cm (exactly)	1 cm = 0.393701 in
1 ft = 0.3048 m (exactly)	1 m = 3.28084 ft
1 yd = 0.9144 m (exactly)	1 m = 1.09361 yd
1 mile = 1.609344 km (exactly)	1 km = 0.621371 mi

Cubic Measure

US to Metric	Metric to US
1 in^3 = 16.387064 cm^3 (exactly)	1 cm^3 = 0.0610237 in^3
1 ft^3 = 0.0283168 m^3	1 m^3 = 35.314725 ft^3
1 yd^3 = 0.764555 m^3	1 m^3 = 1.30795 yd^3

US Liquid Measure

US to Metric	Metric to US
1 fl oz = 29.5735 ml	1 ml = 0.033814 fl oz
1 fl oz = 0.2957 dl	1 dl = 3.3814 fl oz
1 pt = 0.473176 l	1 l = 2.11338 pt
1 gal = 3.78541 l	1 l = 0.264172 gal

Avoirdupois Weight

US to Metric	Metric to US
1 gr = 0.0647989 g	1 g = 15.4324 gr
1 oz = 28.3495 g	1 g = 0.035274 oz
1 lb = 0.453592 kg	1 kg = 2.20462 lb
1 sh cwt = 0.0453592 t	1 t = 22.0462 sh cwt
1 cwt = 0.0508023 t	1 t = 19.6841 cwt
1 sh ton = 0.907185 t	1 t = 1.10231 sh ton
1 UK ton = 1.01605 t	1 t = 0.984207 UK ton

Square Measure

US to Metric	Metric to US
1 in^2 = 6.4516 cm^2 (exactly)	1 cm^2 = 0.1550003 in^2
1 ft^2 = 0.092903 m^2	1 m^2 = 10.7639 ft^2
1 yd^2 = 0.836127 m^2	1 m^2 = 1.19599 yd^2
1 ac = 0.404686 ha	1 ha = 2.47105 ac
1 mile^2 = 2.58999 km^2	1 km^2 = 0.386102 mi^2

UK Liquid Measure

US to Metric	Metric to US
1 fl oz = 28.4131 ml	1 ml = 0.0351951 fl oz
1 fl oz = 0.2841 dl	1 dl = 3.5195 fl oz
1 pt = 0.568261 l	1 l = 1.75975 pt
1 gal = 4.54609 l	1 l = 0.219969 gal

US Dry Measure

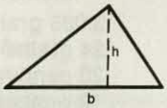
US to Metric	Metric to US
1 pt = 0.550610 l	1 l = 1.81617 pt
1 bu = 35.2391 l	1 l = 0.0283776 bu

Lengths, Areas, and Volumes

The following formulas are used to determine lengths, areas, and heights for common geometric figures.

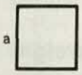
Area of triangle with base b and altitude h

$= \frac{hb}{2}$



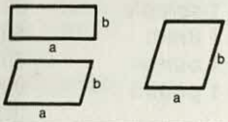
Perimeter of square with side a

$= 4a$



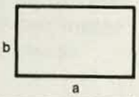
Perimeter of any other parallelogram with sides a and b

$= 2(a + b)$



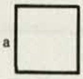
Area of rectangle with sides a and b of unequal length

$= ab$



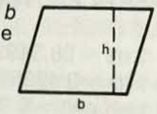
Area of square with side a

$= a^2$



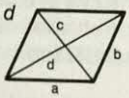
Area of any parallelogram with side b and with h as perpendicular distance from b to side parallel to b

$= bh$



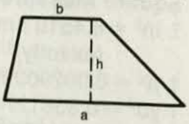
Area of rhombus with diagonals c and d

$= \frac{cd}{2}$



Area of trapezoid with parallel sides a and b and altitude h

$= \frac{h(a + b)}{2}$

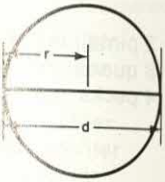


Circumference of circle with radius r

$= 2\pi r$

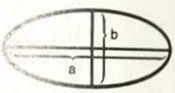
Area of circle with radius r and diameter d $(2r)$

$= \pi r^2 = \frac{1}{4}\pi d^2 = .7854d^2$



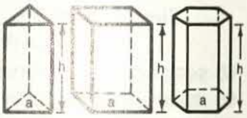
Area of ellipse with major axis a and minor axis b

$= \frac{\pi ab}{4}$



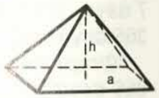
Volume of regular prism with a as area of base and h as altitude

$= ah$



Volume of regular pyramid with a as area of base and h as altitude

$= \frac{ah}{3}$

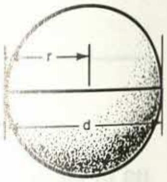


Surface of sphere with radius r and diameter d $(2r)$

$= 4\pi r^2 = \pi d^2 = 12.57r^2$

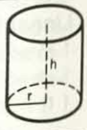
Volume of sphere with radius r and diameter d $(2r)$

$= \frac{4}{3}\pi r^3 = \frac{1}{6}\pi d^3 = 4.189r^3$



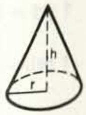
Volume of right cylinder with r as radius of base and with h as altitude

$= \pi r^2 h$



Volume of right cone with r as radius of base and with h as altitude

$= \frac{\pi}{3}r^2 h = 1.047r^2 h$



INDEX

ALPHABETICAL INDEX

The subject headings in this index are usually in the singular form. A subject that is covered by an entire article is printed in boldface capital letters and is followed by the volume and inclusive page numbers, indicating where the article appears in *The New Book of Popular Science*. For example, the entry:

AIR-CUSHION VEHICLE 6–137–38

indicates that an article on air-cushion vehicles can be found in volume 6, pages 137 to 138 inclusive. A subject which is covered within an article is printed in boldface capital and lowercase letters and the volume and specific pages are noted. For example, the entry:

Acceleration (phys.) **3**–173, 175, 179

indicates that information on acceleration can be found on pages 173, 175, and 179 of volume 3. If a subject is covered in a labeled section of several pages within an article, only the first page number of the section is given. In all text references, volume numbers are printed in boldface type, page numbers in lightface type. Multiple volume and page references to one subject are generally filed in numerical order. However, if one reference is to a substantial description of a topic this reference is listed before the less important references. For example:

Absolute zero (phys.) **3**–368, 12, 198

If a subject is mentioned on three or more successive pages, the first number will be noted with the indication "fol." as in this example:

Afferent fiber (anat.) **5**–261 fol.

Illustrations are identified by the abbreviation *illus.* References to illustrations are filed after all references to the text.

Subjects in this index may be subdivided to make information on specific aspects of the topic readily accessible. These subentries are indented and listed alphabetically below the main entry. The example below has three subentries.

Acceleration (phys.) **3**–173, 175, 179
  airliner **1**–259
  gravitational **3**–166
  space flights' effects on astronauts **1**–273

Many entries include a brief identification of the subject. The identification, enclosed in parentheses, may note the scientific field in which the term is commonly used, define the subject in a few words, or describe a person's nationality and profession.

Aardwolf (zool.) **5**–96; *illus.* **5**–96
Abacus (calculating device), *illus.* **1**–346
Adams, John Couch (Eng. astron.) **1**–89; **3**–165

The index includes *see* and *see also* references. *See* references guide the reader from one term to another. They are used for abbreviations, for synonyms, for inverted headings, and for alternative spellings.

Accelerator, Atomic *see* Atom smasher
ALU *see* Arithmetic and logic unit
Amoeba *see* Ameba
Ascorbic acid *see* Vitamin C

See also references direct the reader to related subject entries.

Astrogeology (sci.) **1**–301
  See also Moon, Geology of the
Atomic theory (phys.) **3**–310, 311
  See also Atom

Subjects are filed alphabetically, letter by letter. When a subject heading is made up of more than one word it is still arranged alphabetically, letter by letter.

Air (gas)
  circulation **2**–126
  composition and weight **3**–189
Airglow (atmospheric phenomenon) **2**–111, 112
Air-lift pump 2–438; *illus.* **2**–437
Airline-reservation system 1–460, 471
Air mass (meteorol.) **2**–133
Airplane 6–104 fol.

ABBREVIATIONS USED IN THE INDEX

A

adm. admiral
aero. aeronaut; aeronautics; aeronautical
Afr. Africa; African
agr. agriculture; agricultural; agriculturalist
Alas. Alaska
Alta. Alberta
Amer. America; American
anat. anatomy; anatomist
anc. ancient
anthro. anthropology; anthropologist
arch. architecture; architect; architectural
archaeo. archaeology; archaeological; archaeologist
Ariz. Arizona
art. artist
astro. astronaut; astronautics; astronautical
astron. astronomy; astronomer; astronomical
Aus. Austria; Austrian
Austr. Australia; Australian
auto. automobile

B

bact. bacteria; bacteriology; bacteriologist
B.C. British Columbia
biochem. biochemistry; biochemist
biol. biology; biologist
bio-phys. biophysics; biophysicist
bot. botany; botanist
Braz. Brazil; Brazilian
Brit. British
Bulg. Bulgaria; Bulgarian

C

Calif. California
Can. Canada; Canadian
capt. captain
Carib. Caribbean
cartog. cartography; cartographer
Chan. Isls. Channel Islands
chem. chemistry; chemist
cler. clergyman

D

Dan. Danish
dent. dentist; dentistry
dept. department
diag. diagram
Du. Dutch

E

Egy. Egypt; Egyptian
elec. electrical; electricity
electron. electronic; electronics
elem. element
embryol. embryology; embryologist
emp. emperor; empire; empress
Eng. England; English
eng. engineering; engineer
entom. entomology; entomologist
Eur. Europe; European
expl. explorer
ext. extinct

F

Fla. Florida
Flem. Flemish
fol. following
for. forestry
Fr. France; French

G

Ga. Georgia
geog. geography; geographer
geol. geology; geologist
geom. geometry
Ger. Germany; German
Gr. Greece; Greek
gynecol. gynecology; gynecologist

H

Haw. Hawaii, Hawaiian
herp. herpetology; herpetologist
Hung. Hungary; Hungarian

I

Ice. Iceland; Icelandic
ichth. ichthyology; ichthyologist
Ill. Illinois
illus. illustration
Indon. Indonesia; Indonesian
indus. industry; industrialist
instru. instrument
inv. inventor
Ir. Irish
isl., isls. island; islands
It. Italian; Italy

J

Jap. Japan; Japanese

K

Ky. Kentucky

L

lieut. lieutenant

M

mach. machine
Mass. Massachusetts
math. mathematics; mathematician
Me. Maine
meas. measure; measurement
mech. mechanics; mechanic; mechanical
med. medicine; medical
metal. metallurgy; metallurgist
meteorol. meteorology; meteorologist
Mex. Mexico; Mexican
mil. military
min. mineral; mineralogy; mineralogist; mining
Mont. Montana
MS.; ms. manuscript
mt.; mts. mount; mountain; mountains
mus. music; musician; musical; musicologist

N

N.Afr. North Africa
N.Amer. North America
nat. naturalist
nav. naval
N.C. North Carolina
Newf. Newfoundland
N.H. New Hampshire
N.Mex. New Mexico
nov. novel; novelist
N.Y. New York State
N.Y.C. New York City

O

oceanog. oceanography; oceanographer; oceanographic
Okla. Oklahoma
Ont. Ontario
ophthal. ophthalmology; ophthalmologist
Oreg. Oregon
ornith. ornithology; ornithologist

P

Pa. Pennsylvania
Pac.O. Pacific Ocean
paleon. paleontology; paleontologist
path. pathology; pathologist
Pers. Persia; Persian
Philipp. Philippines
philos. philosophy; philosopher; philosophic
phot. photography; photographer
phy. physician
phys. physics; physicist
physiog. physiography
physiol. physiology; physiologist
Pol. Poland; Polish
Port. Portugal; Portuguese
P.R. Puerto Rico, Puerto Rican
psych. psychology; psychologist

R

Rom. Roman
Russ. Russia; Russian

S

S. South; Southern
S.Afr. South Africa; South African
S.Amer. South America; South American
Sask. Saskatchewan
schol. scholar
sci. science; scientist
Scot. Scotland; Scottish
sculp. sculpture; sculptor
S.Dak. South Dakota
Sib. Siberia
Sic. Sicily; Sicilian
Sov. Soviet
states. statesman
surg. surgery; surgeon; surgical
Swed. Sweden; Swedish
Switz. Switzerland

T

Tanz. Tanzania; Tanzanian
tel. telephone
teleg. telegraphy
Tex. Texas
theol. theology; theologian
trig. trigonometry
TV television

U

U.S. United States
USSR Union of Soviet Socialist Republics

V

v. versus
Va. Virginia
volc. volcano; volcanic

W

Wash. Washington
Wis. Wisconsin
writ. writer
W.Va. West Virginia
Wyo. Wyoming

Y

Yugos. Yugoslavia; Yugoslav

Z

zool. zoology; zoologist

A

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